Comparison of Four Numerical Methods of EHL Modeling

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TECHNOLOGICAL
INSTITUTE

Edited by

Lars Pleth Nielsen
Ion Marius Sivebæk
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PROGRAMME OVERVIEW

AND

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NORDTRIB 2014 PROGRAMME

	TUESDAY 10 JUNE 2014			WEDNESDAY 11 JUNE 2014			THURSDAY 12 JUNE 2014			FRIDAY 13 JUNE 2014		
08.40 – 09.00	*It is possible to put up posters during the day*			PLENARY 2 - *Chair S. S. Eskildsen* **Professor Martin Priest**			PLENARY 3 - *Chair I.M. Sivebæk* **Professor Mathew Mate**			PLENARY 4 – *Chair I.M. Sivebæk* **Professor Martin Müser**		
09.00 – 09.20												
09.20 – 09.40				Coffee break			Coffee break			Coffee break		
				Suecia	Dania	Nortvegia	Suecia	Dania	Nortvegia	Suecia	Dania	Nortvegia
				Abrasion *J. Jakobsen*	*IC Engine* *S.S. Eskildsen*	*Adh. & Friction* *J. Juoksukangas*	*Coatings 1* *H. Ronkainen*	*Ind. Trib. 1* *H. Torres*	*Lubrication 1* *P. Klit*	*Ind. Trib. 2* *A Lehtovaara*	*Bearings* *M. Müser*	*Trib. of Mater.* *S. Jacobson*
09.40 – 10.00	**REGISTRATION**			125	128	22	142	143	77	101	141	15
10.00 – 10.20				74	120	97	6	27	119	48	129	25
10.20 – 10.40				28	105	87	50	78	45	40	127	133
10.40 – 11.00				30	140	99			88	29	121	
11.00 – 11.20				60			65	95	89	33	66	57
11.20 – 11.40				Coffee break			Coffee break			**CLOSING REMARKS** **Lars Pleth Nielsen 11.20**		
				Wear *M. Priest*	*Test Meth. 1* *B.H. Christensen*	*Bio Tribology* *L.P. Nielsen*	*Coatings 2* *A. Cavaleiro*	*Polymer 1* *I.M. Sivebæk*	*Lubrication 2* *M. Mate*			
11.40 – 12.00				23	13			122	98	**Coffee break and lunch from 11.40**		
12.00 – 12.20	**LUNCH 12.00-13.00**			84	42	7	139	130	115			
12.20 – 12.40				56	14	86	144	35	26			
12.40 – 13.00				68	76		137	75	2			
13.00 – 13.30	WELCOME			**LUNCH 13.00-14.00**			**LUNCH 13.00-14.00**					
13.30 – 14.10* **Tuesday only*	PLENARY 1 – *Chair L.P. Nielsen* **Professor Albano Cavaleiro**											
	Suecia	Dania	Nortvegia	*Wear & Fret.* *S. Glavatskih*	*Test Meth. 2* *D. Drees*	*Modelling 3* *K. Tønder*	*Coatings 3* *N. Espallargas*	*Polymer 2* *Y. Sawae*	*Brakes* *I. Santos*			
	Trib Chemistry *S. Louring*	*Wear & Lubr.* *K. Valtonen*	*Modelling 1* *K. Holmberg*									
14.00 – 14.20				21	36	16	73	116				
14.20 – 14.40	1	67	18	37	38	83	126	8	100			
14.40 – 15.00	62	134		49	39	24	72	11	61			
15.00 – 15.20	104	118	80	54	94	92	96	81	124			
15.20 – 15.40	Coffee break			Coffee break			Coffee break					
	Mach. Elem. *R. Larsson*	*Texturing* *K.P. Almtoft*	*Modelling 2* *U. Olofsson*	*15.40-17.00* *POSTER SESSION (Nortvegia)*			*Test Meth. 3* *M. Varga*	*Polymer 3* *J. Sukumaran*	*Lubrication 3* *T. Norrby*			
15.40 – 16.00	17	3	10				109	64	47			
16.00 – 16.20	19		53	4, 20, 31, 32, 43, 52, 63, 69,			145	34	12			
16.20 – 16.40	106	41	135	70, 82, 90, 91, 103, 111, 117, 131, 138					146			
16.40 – 17.00	102	108	9									
	Departure by bus at 17.15			*Departure by bus at 17.15*			*Departure by bus at 17.30*					
	17.30-22.00 Danish Technological Institute Tribology Centre + Add. Manufacturing			**17.30-22.00 "Student for a night"**			**18.30-23.00 Concert and Conference Dinner**					

	Tuesday 10 June 2014		
09.40	Registration (Lunch 12:00-13:00)		
13:00	**Opening Session** **by the Mayor of Aarhus Jacob Bundsgaard**		
13:30	**Plenary session 1 - Professor Albano Cavaleiro:** **Close to zero friction of sliding induced self-alignment of transition metal dichalcogenides coatings** *Chair: Lars Pleth Nielsen*		
Room	*Suecia*	*Dania*	*Nortvegia*
	Tribo Chemistry *Chair: Sascha Louring*	**Wear & Lubrication** *Chair: Kati Valtonen*	**Modelling 1** *Chair: Kenneth Holmberg*
14:20	Study the lubrication behavior of chemical mechanical polishing (CMP) of highly boron-doped polysilicon at moderate and high polish velocities (1) *Hamidreza Pirayesh, Dr. Ken Cadien*	The Failure and Damage Mechanisms under Friction of Copper in the EHL and Mixed EHL Regions (67) *A. Moshkovich, I. Lapsker, A. Laikhtman, V. Perfilyev, L. Rapoport*	Atomistic origins of tribologically induced metallic surface folding (18) *Nils Beckmann, Pedro Romero, Michael Moseler and Peter Gumbsch*
14:40	Effect of normal load on multi-degradation mechanisms of super duplex stainless steel exposed to tribocorrosive-fatigue environment (62) *Amin H. Zavieh, Nuria Espallargas*	Proposal of invariant precursor for boundary lubricated scuffing (134) *Łukasz Wojciechowski, Thomas G. Mathia*	
15:00	Neutron reflectometry of boundary films on DLC coatings (104) *Rok Simič, Mitjan Kalin, Tomoko Hirayama*	Influence of Physical States of Amide Type Gel-Lubricants on Tribological and Rheological Properties (118) *Kazumi Sakai, Yuji Shitara*	Combined consideration of qualitive and quantative factors in computer modeling of tribological systems (80) *Lev Evelson, Mayya Rafalovskaya*
15:20	Coffee Break		

Room	*Suecia*	*Dania*	*Nortvegia*
	Machine Elements *Chair: Ronald Larsson*	**Texturing** *Chair: Klaus P. Almtoft*	**Modelling 2** *Chair: Ulf Olofsson*
15:40	Rolling Contact Fatigue Of Hydrogen Infused Bearing Surfaces Under An Applied Hoop Stress And EHL Conditions (17) *Shravan Janakiraman, Ole West, Peder Klit, Niels Jensen*	Effect of counterface roughness on adhesion of mushroom-shaped microstructure (3) *Haytam Kasem, Michael Varenberg*	Simulation of a Hydraulic Rod Seal with a Micro-Patterned Rod (10) *Yuli Huang and Richard F. Salant*
16:00	On the Running-In Behaviour of Lubricated Line Contacts (19) *Thomas Lohner, Josef Mayer, Klaus Michaelis, Bernd-Robert Höhn, Karsten Stahl*		Roughness Evolution in Mixed Lubrication Condition due to Mild Wear (53) *G. E. Morales Espejel, V. Brizmer*
16:20	In situ surface characterization of running-in of involute gears (106) *MSc. Mario J. Sosa, Dr. Stefan Björklund, Dr. Ulf Sellgren, Prof. Ulf Olofsson*	The effect of oil pockets array on tribological behaviour of sliding elements (41) *Slawomir Wos, Waldemar Koszela and Pawel Pawlus*	Model for Contact Area between Finger and Sinusoidal Plane to Evaluate Adhesion and Deformation Component of Friction (135) *K. Duvefelt, U. Olofsson, C.M. Johannesson, L. Skedung*
16:40	A study on surface influence on gear efficiency and lubricant temperature (102) *Martin Andersson, Ulf Olofsson, Stefan Björklund*	Application of fractal analysis to diagnose contact interaction of frictional solid objects (108) *A.M, Pashayev, A.Kh. Janahmadov, N.G. Javadov, M.Y. Javadov*	Theoretical Analysis of the Local Load Situation of Rough Surfaces (9) *Balázs Magyar, Bernd Sauer*
17:15	Departure by bus DTI – Tribology Centre, Materials and Surfaces and Product Development		

	Wednesday 11 June 2014		
08:40	**Plenary session 2 – Professor Martin Priest:** **Friction and Durability of the Piston/Cylinder Interface in Reciprocating Engines** *Chair: Svend Stensig Eskildsen*		
09:20	Coffee Break		
Room	*Suecia*	*Dania*	*Nortvegia*
	Abrasion *Chair: Jørgen Jakobsen*	**IC Engine** *Chair: Svend S. Eskildsen*	**Adhesion & Friction** *Chair: Janne Juoksukangas*
09:40	Erosive and abrasive wear resistance of carbide free bainitic steels (125) *Esa Vuorinen, Christoph Rau, Christian Gahm*	Experimental Investigation of the Tribological Behaviour of Cylinder Liner – Piston Ring Contact with High Pressure Difference Across Ring Pack (128) *Peder Klit, Anders Vølund*	Integrated surface chemistry and roughness characterization to study wetting and adhesion behavior (22) *Jyrki Korpela, Susanna Laurén and Maiju Pykönen*
10:00	Influence of hardness and microstructure on the mechanisms of deformation and wear of cemented carbides for rock drilling (74) *Jannica Heinrichs, Karin Yvell, Mikael Olsson, Staffan Jacobson*	The lubricity of diethyl ether (DEE) (120) *Sivebaek I. M., Jacobsen J.*	The effect of surface roughness and carbon coatings on the friction performance in rolling contact (97) *H. Ronkainen, L. Kilpi, S. Varjus, O. Elomaa, J. Koskinen, T. Jaatinen, J. Toikkanen*
10:20	Abrasive wear of CVD α-Al2O3 and Ti(C,N) coatings at room and elevated temperature (28) *Mikael Fallqvist and Rachid M´Saoubi*	Testing scuffing resistance of materials for marine 2-stroke engines – Difficulties with lab scale testing of a complex phenomenon (105) *Petra Olander, Svend S. Eskildsen, Jesper Weis Fogh, Patrik Hollman and Staffan Jacobson*	Integrated characterisation and functional testing of friction-locking surfaces (87) *Matthias Gräfensteiner, Erhard Leidich*
10:40	Nanotribological simulations of multi-grit polishing and grinding (30) *A Pauschitz, S.J. Eder, D. Bianchi, U. Cihak-Bayr, A. Vernes, and G. Betz*	Investigation on friction properties of nickel ceramic electrodeposits (140) *Io Mizushima, Per Møller and Anette Alsted Rasmussen*	Friction property of DLC films in low-pressured hydrogen condition (99) *Hikaru Okubo, Hirochika hukuda, Ryo Tsuboi, Shinya Sasaki*

Room	*Suecia*	*Dania*	*Nortvegia*
11:00	Microstructure refinement effect on two-body abrasion resistance of white cast irons (60) *Jimmy Penagos, Fernando Satoshi, Amilton Sinatora, Eduardo Albertin*		
11:20	Coffee Break		
	Wear *Chair: Martin Priest*	**Test Methods 1** *Chair: Bjarke H. Christensen*	**Bio Tribology** *Chair: Lars P. Nielsen*
11:40	Rolling-sliding wear of nodular cast iron rollers against wire ropes (23) *Ville Oksanen, Kati Valtonen, Peter Andersson, Antti Vaajoki, Anssi Laukkanen, Kenneth Holmberg, Veli-Tapani Kuokkala*	The use of high temperature nanomechanics in designing coatings with improved wear resistance in high-speed machining (13) *Ben Beake, Adrian Harris and Mike Davies*	
12:00	Initiation of wood defibration, tribology at the fiber level (84) *Magnus Heldin, Urban Wiklund, Per Isaksson, Staffan Jacobson*	Introduction of a novel AC²T tribometer especially designed for harsh environment scratch-, adhesion- and hardness investigation up to 1000°C (42) *M. Varga, M. Flasch, S. Paar, E. Badisch*	The influence of diamond like carbon coated surfaces on friction and film thickness to a bovine ceramic lubrication condition (7) *Dipankar Choudhury, Fadi Ali, Martin Vrbka, Ivan Krupka, Martin Hartl*
12:20	Sliding Wear of Quartz and Granite Surfaces (56) *V. Heino, K. Valtonen, V.-T. Kuokkala*	Extreme nanomechanics: overcoming the challenges in vacuum nanoindentation to 1000 °C (14) *Ben Beake, Mike Davies and Adrian Harris*	Studying Water Behavior Under Reciprocating Situation in Micro-Channel (86) Alaleh Safari, Michel J.Cervantes, Nazanin Emami
12:40	The effect of stick-slips on the dislocation structure of LiF single crystals (68) *A.Moshkovich, I. Lapsker, A. Laikhtman, V. Perfilyev, L. Rapoport*	Effect of temperature control in high temperature tribology (76) *Kirankumar P. Jayananda, Anshuman Dube, Amit Ganguly, Deepak H.Veeregowda*	
13:00	Lunch 13:00 – 14:00		

Room	*Suecia*	*Dania*	*Nortvegia*
	Wear & Fretting *Chair: Sergei Glavatskih*	**Test Methods 2** *Chair: Dirk Drees*	**Modelling 3** *Chair: Kristian Tønder*
14:00	Computational multiscale modelling concept and supporting experimental testing procedures for material wear behaviour under severe environments (21) *Anssi Laukkanen, Päivi Kivikytö-Reponen, Antti Vaajoki, Richard Waudby, Tom Andersson, Marjaana Karhu, Marian Apostol, Kati Valtonen, Veli-Tapani Kuokkala*	Film thickness measurements in a running hydrostatic swash plate type unit using ultrasound (36) *Sünje Marsch, Lars Leonhard, Marc Diesselberg, Phil Harper, Rob S. Dwyer-Joyce*	Cavitation analysis of a journal bearing - Finite Element modelling and experimental studies (16) *C.K. Christiansen, P. Klit, J.H. Walther, A. Vølund*
14:20	Effect of the contact angle on the impact-sliding wear of nitrided stainless steel at 400˚C (37) *Takahiro Yamazaki, Junichi Yoshihisa, Jean-Christophe Abry, Gaëton Bouvard, Vincent Fridrici) and Philippe Kapsa*	Validation of a New Tribological Test Bench for Lightweight Hydraulic Components (38) *Markus Blust, Benoit Lorentz*	Dynamic and tribological analysis of a toroidal CVT (83) *Keith Philpot and Romeo Glovnea*
14:40	Applying the digital image correlation method to fretting contact (49) *J. Juoksukangas, A. Lehtovaara, A. Mäntylä*	Test rig for drag force measurements (39) *Bihotz Pinedo, Jose Mª Seara, Joseba Arana, Raquel Bayon, Amaya Igartua*	Comparison of Four Numerical Methods of EHL Modeling (24) *Shravan Janakiraman, Peder Klit*
15:00	Fretting wear behaviour of MoS_2 dry film lubricant (54) *K. Barman, K.T. Voisey, P.H. Shipway, G.A. Pattinson*	Surface plasmon resonance measurements of adsorbed films under fluid lubrication conditions (94) *Satoru Maegawa, Anna Koseki, Fumihiro Itoigawa, Takashi Nakamura*	A Non-Newtonian THD Lubrication Model for Journal Bearings (92) *Shiuh-Hwa Shyu, Shen-Min Liang, Tz-Ting Chiou and Jyun-Jye Liao*
15:20	Coffee Break		

15:40	**POSTER SESSION - ROOM NORTVEGIA**		
15:40 - 17:00	Modelling of nonlinear dynamic of mechanic systems with the force tribological interaction (4) *Victor Musalimov, Konstantin Nuzhdin, Irina Kalapyshina*	Researches on the Friction between the Guide made of Phosphor Bronze and the Valve Stem made of Ti_6Al_4V with and without Protective Layer (20) *Maciej Kuchar, Krzysztof Jan Siczek*	Tribological Analysis of the Nano-modified Industrial Polymer (31) *Olga Konovalovaa, Jan Suchanek*
	Wear and Mechanical properties of nodular iron modified with copper (32) *V. Gil; F. Alcalá; F. Correa; N.C. Alba; J. Ramos*	Observation of Elastic/Plastic Response of Adsorbed Mono-Layer to Friction by Lateral Force Microscopy (43) *Fumihiro ITOIGAWA, Mina WAKAMATSU, Takashi NAKAMURA*	The Resource Estimation of heavy-loaded friction units of internal combustion engine (52) *E. Zadorozhnaya, I. Levanov*
	Tribological properties of friction pair Al_2O_3/IF-WS_2 composite layer with the TG15 plastic (63) *J. Korzekwa, J. Pietraszek, W. Skoneczny*	Tribological behavior of epoxy and epoxy composites (69) *Iulia GRAUR, Marina BUNEA, Iulian-Gabriel BÎRSAN, Vasile BRIA, Adrian CÎRCIUMARU*	Tribological analysis of fabric reinforced epoxy composites (70) *Marina BUNEA, IULIA GRAUR, Adrian CÎRCIUMARU, Vasile BRIA, Iulian-Gabriel BÎRSAN*
	Flammability of vegetal oils on hot surface (82) *L.C. Solea, C. Georgescu, L. Deleanu*	Virtual evaluation of manufactured surfaces – to use 3D data to predict performance (90) *P-J Lööf, B.-G. Rosén , F. Cabanettes*	Modern Methods for Estimation of Triboresistance during Nanoscanning of Fiberglass Surfaces (91) *Victor Musalimov, Pavel Kovalenko, Svetlana Perepelkina*
	Tribological study of some multilayered ceramic structures in the aeronautical industry (103) *V.Manoliu, Gh.Ionescu, A.Stefan, A.Mihailescu,S.Ivan*	Study of Torque and Thrust of needle roller bearings (111) *Tetsuzo Hatazawa and Takahisa Kawaguchi*	Friction of W-DLC(H) - testing in laboratory and motorcycle engine (117) *P. Mutafov, J. Lanigan, A. Neville, A. Cavaleiro, T. Polcar*

Room	*Suecia*	*Dania*	*Nortvegia*
	Laboratory Investigations about the Mechanisms of Aluminium Transfer on Hot Forming Tools (131) *Jaume Pujante, Giselle Ramírez, Nuria Cuadrado, Montserrat Vilaseca, Daniel Casellas*	TiO_2 and TiO_2/Ag nanotubes as coatings for modern dental implants (138) *Ż. Muchewicz, A. Radtke, P. Piszczek, T. Jędrzejewski, W. Kozak, S. Kąc*	
17:15	Departure by bus ”Student for a night”		

	THURSDAY 12 JUNE 2014		
08:40	**Plenary session 3 – Mathew Mate:** **Improved Understanding of Lubrication at the Molecular level and its Impact on Technology** *Chair: Ion Marius Sivebæk*		
Room	*Suecia*	*Dania*	*Nortvegia*
	Coatings 1 *Chair: Helena Ronkainen*	**Industrial Tribology 1** *Chair: Hector Torres*	**Lubrication 1** *Chair: Peder Klit*
09:40	Tribological and mechanical properties of Cr_2N-11Ag – coatings deposited on Cr-V ledeburitic steel (142) *Pavel Bílek, Peter Jurči, Michal Novák, Mária Hudáková, Ľubomír Čaplovič*	Three – body abrasion behavior of selected commercially available polymer materials (143) *Vladimir Pejaković, Robin Jisa, Friedrich Franek*	Adsorption of ATF additives on wet clutch friction interfaces under various lubricant conditions (77) *Nowshir Fatima, Kim Berglund, Allan Holmgren, Pär Marklund, Roland Larsson*
10:00	Friction investigation with thermally sprayed Fe-based coatings for application on cylinder running surfaces in combustion engines (6) *Beate Schleif, Wolfram Wagener, Ludger Deters*	New tribo-systems for sheet metal forming of advanced high strength steels and stainless steels (27) *E. Ceron, N. Bay*	The viscosity of Dimethyl Ether (DME) determined by Quartz Crystal Micro-balance (QCM) (119) *Hansen A., Rechter C., Sivebaek I.M., Jacobsen J.*
10:20	Friction and wear resistance of plasmapolymeric coatings applied on elastomers (50) *Dominik Paulkowski, Stefanie Karpinski, Klaus Vissing*	Development of diffusion couple method to study chemical interactions between cemented carbide and difficult to machine materials (78) *L. v Fieandt, R. M'Saoubi, B Jansson, M. Schwind, C. Århammar*	Characterization of start-stop motions – a novel approach (45) *Frederik Wolf, Kartik Pondicherry*
10:40		Laboratory Investigations about the Mechanisms of Aluminium Transfer on Hot Forming Tools (131) *Jaume Pujante, Giselle Ramírez, Nuria Cuadrado, Montserrat Vilaseca, Daniel Casellas*	Feedback-Controlled Lubrication for Reducing the Lateral Vibration of Flexible Rotors supported by Tilting-Pad Journal Bearings (88) *J.G. Salazar, I.F. Santos*

	Suecia	*Dania*	*Nortvegia*
11:00	Evaluation of Durability of SOG-layers on Steel Surfaces by Wear and Scratch Tests (65) *Z. Dimkovski, G. Kofod, S. Rebeggiani, B.-G. Rosén*	Design of an axially concave pad profile for a large turbine tilting-pad bearing (95) *B. Bender, Nico Buchhorn, Sebastian Kukla*	Tribofilms of MoS_2 nanotubes on steel and DLC-coated surfaces (89) *Janez Kogovšek, Janez Kovač, Maja Remškar, Mitjan Kalin*
11:20	Coffee Break		
	Coatings 2 *Chair: Albano Cavaleiro*	**Polymer 1** *Chair: Ion M. Sivebæk*	**Lubrication 2** *Chair: Mathew Mate*
11:40		The impact of the standard turbine oil and the bio-degradable synthethic oil on properties of the polymers used as sliding layers in the hydrodynamic thrust bearings. (122) *Michal Strankowski, Michal Wasilczuk, Justyna Zorn*	Lubricating properties of MR fluid (98) *Shinnosuke Yano, Shinji Kato, Ryo Tsuboi, Shinya Sasaki*
12:00	Integration of HiPIMS Equipment into an Industrial Coating Production for Cutting Tools (139) *Toni Leyendecker, Oliver Lemmer, Werner Kölker, Christoph Schiffers*	Friction and wear studies of some PEEK materials (130) *Jonna Holmgren, Per O. Lindholm, Jian Qin and Åsa Kassman Rudolphi*	EHL Traction Analysis of Perfluoropolyether Fluids Based on Bulk Modulus (115) *Nobuyoshi Ohno, Toshifumi Mawatari, Bo Zhang, Motohiro Kaneta, Petr Sperka, Ivan Krupka and Martin Hartl*
12:20	Characterisation of Nanocomposite Ti-C-N Coatings Deposited by Industrial-Scale DC Magnetron Sputtering for Tribological Applications (144) *Sascha Louring, Bjarke Holl Christensen, Klaus Pagh Almtoft and Lars Pleth Nielsen*	Tribological behaviour of peek/MoS_2 composites: Influence of MoS_2 particles concentration and processing temperature (35) *Maša Zalaznik, Mitjan Kalin, Saša Novak Krmpotič*	EHL for lubricated contacts of DLC – role of interfacial and contact properties (26) *M. Polajnar, M. Kalin*
12:40	The effect of V additions on the tribological behaviour of sputtered TiSi(V)N coatings at room temperature (137) *Filipe Fernandes, Tomas Polcar, Albano Cavaleiro*	Low Wear of Carbon Fiber Filled PTFE in Gaseous Hydrogen (75) *Yoshinori Sawae, Kazumi Okada, Takehiro Morita, Yoshie Kurono3, Joichi Sugimura*	Overcoming starvation in EHL point contacts by enhanced replenishment (2) *F.Ali, I.Křupka, M.Hartl*
13:00	Lunch 13.00 – 14.00		

	Suecia	*Dania*	*Nortvegia*
	Coatings 3 *Chair: Nuria Espallargas*	**Polymer 2** *Chair: Yoshinora Sawae*	**Brakes** *Chair: Ilmar Santos*
14:00	On the low friction of W-S-N coatings (73) *Jill Sundberg, Harald Nyberg, Erik Särhammar, Tomas Nyberg, Staffan Jacobson, Ulf Jansson*	An unconventional approach in polymer wear: Online vision system (116) *Jacob Sukumaran, Seyfollah Soleimani, Vanessa Rodriguez, Wilfried Philips, Patrick. De Baets*	
14:20	Enhanced contact fatigue behavior of coated tool steel by using W-C:H thin film (126) *Giselle Ramírez, Emilio Jiménez-Piqué, Alvaro Mestra, Montserrat Vilaseca, Daniel Casellas, Luis Llanes*	Erosion wear of glass fibre reinforced vinylester (8) *Reija Suihkonen, Juuso Perolainen, Mari Lindgren, Kati Valtonen, Niko Ojala, Jyrki Vuorinen*	Influence of pin contact geometry and friction material behavior on disc brake squeal noise (100) *M. Duboc, J.F. Brunel , V. Magnier, P. Dufrénoy*
14:40	Performance of WS_2-based coatings under lubricated sliding (72) *Harald Nyberg, Jill Sundberg, Erik Särhammar, Tomas Nyberg, Ulf Jansson, Staffan Jacobson*	The Wear and Thermal Mechanical contact Behaviour of Polymer Gears (11) *Dr. Ken Mao and Dr. Wei Li*	Influence of snow on train block braking performance – a pin on disc simulation in a climate chamber (61) *Ulf Olofsson, Jon Sundh, Ulf Bik and Rickard Nilsson*
15:00	The effects of aging and elevated temperatures on of DLC films (96) *H. Ronkainen, K. Holmberg, A. Laukkanen*	Wear resistance of polymeric materials based on PBT (81) *M. Botan, C. Pirvu, C. Georgescu, L. Deleanu*	Brass in brake lining: elements of understanding for its replacement (124) *M. Baklouti, A.L. Cristol, R. Elleuch, Y. Desplanques*
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	Test Meth. 3 *Chair: Markus Varga*	**Polymer 3** *Chair: Jacob Sukumaran*	**Lubrication 3** *Chair: Thomas Norrby*
15:40	Improvements to Tribological Testing for industry, Practical solutions (109) *D. Drees, E. Georgiou*	On the existence of a friction-modified surface layer of BR/SSBR elastomers reinforced with different silica or carbon black contents (64) *Milad Mokhtari, Dirk J. Schipper and Tetyana V. Tolpekina*	Grease free surface flow on a rotating plate (47) *J. X. LI, Lars G. Westerberg, E. Höglund , T. S. Lundström*

	Suecia	*Dania*	*Nortvegia*
16:00	Scratch & Failure Detection Method for Shaft and Rod Surfaces (145) *F. Bauer, M. Baumann, W. Haas*	The role of frictional work in tribological behavior of polyamide 66 composites containing hard particles (34) *Kei Shibata, Takeshi Yamaguchi, Moeko Kishi and Kazuo Hokkirigawa*	Grease + Water = fatal attraction? (12) *Johan Leckner*
16:20			Novel energy efficient biodegradable turbine oil (146) *Thomas Norrby, Åke Byheden, Sergei Glavatskih*
17:30	Departure by bus Concert and Conference Dinner		

	Friday 13 June 2014		
08:40	**Plenary session 4 – Professor Martin Müser:** **Friction mechanisms at small and large scales: New insights from computer simulations** *Chair: Ion Marius Sivebæk*		
Room	*Suecia*	*Dania*	*Nortvegia*
	Industrial Tribology 2 *Chair: Arto Lehtovaara*	**Bearings** *Chair: Martin Müser*	**Tribology of Materials** *Chair: Staffan Jacobsson*
09:40	Influence of switching speed of connectors in conditions of engaging and separating with electrical load (101) *Alexander Hornung, Frank Berger, George Freudiger, Tom Ledermann*	Crack propagation in silicon nitride bearing elements (141) *W. Karaszewski*	Friction and wear characteristics of different Pb-free bearing materials in mixed and boundary lubrication regimes (15) *Daniel W. Gebretsadik, Jens Hardell, Braham Prakash*
10:00	Formation and degradation of protective tribofilms on diesel engine valve surfaces (48) *Robin Elo, Staffan Jacobson*	Application of multilobe journal bearings in grinding machines spindle systems (129) *Zdzislaw SOCHA, Stanislaw STRZELECKI*	The effect of sliding distance and temperature on the initiation and formation of the aluminium alloy transfer to the uncoated and coated tool steel (25) *J. Jerina, M. Kalin*
10:20	Comprehensive study of wear phenomena during hot rolling of steel (40) *H. Torres, M. Varga, U. Cihak-Bayr, K. Adam, E. Badisch*	Experimental Investigation of Fatigue Lifetime for Bearing Materials in Large Two-stroke Marine Diesel Engines (127) *Peder Klit, Sebastian Persson and Anders Vølund*	A pin on disc study of the tribology characteristics of sintered versus standard gear materials (133) *Xinmin Li, Mario Sosa, Ulf Olofsson*
10:40	Friction behaviour of phosphate-free lubricants for steel wire drawing (29) *M. Vilaseca, J. Vidal, J. Pujante, G. Ramírez, N. Cuadrado, D. Casellas*	Pressurized oil supply in cylindrical 2-grooves journal bearing (121) *Standziak G. , Strzelecki S.*	

	Suecia	*Dania*	*Nortvegia*
11:00	Development of new tapping tool covered with nickel/abrasive particles composite film (33) *<u>Yasuyoshi Saito</u>, Takeshi Yamaguchi, Kei Shibata, Yuki Kadota, Takeshi Kubo, Wataru Watanabe, Teruo Sawabe, and Kazuo Hokkirigawa*	Solution for deposition on bearing pads by insoluble particulates in turbine oils (66) *<u>Fumihiko Yokoyama</u>, Yuka Iwama, Yuka, Otsuka, Masahiro Maruyama, Mitsuo Sano*	Adhesive strength of coated film by aerosol deposition using reactive alumina submicron powder (57) *<u>Yuji Ohue</u>, Yuta Haratsuka, Yukihisa Tamura*
11:20	CLOSING REMARKS by Lars Pleth Nielsen		
11:40	Coffee and Lunch from 11:40		

CONTENTS

PLENARY SESSION 1

Tuesday 10 June 2014 - 13.30-14.10

Professor Albano Cavaleiro

Chair: Lars Pleth Nielsen

Close to zero friction of sliding induced self-alignment of transition metal dichalcogenides coatings

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Abstract:

The reported possibility to achieve super low friction (friction coefficient less than 0.01) in particular sliding conditions has been the driving force for extensive research studies performed in the field of coatings tribology. In last decades, transition metal dichalcogenides (TMD) have been a potential solution for this requirement due to their layered structure and weak inter-layer bonding allowing decreasing friction in mechanical contacts. Unfortunately, two main drawbacks of these materials have hindered a more extensive use in the field of low friction coatings, their high sensibility to moisture and their low loading bearing capacity. Therefore, the main research studies in this field have been the alloying of TMD in order to overcome those drawbacks. Our approach that goes beyond the state-of-the-art is to control the deposition parameters, including the type and amount of alloying element, in order to tailor the structure at nanometer level allowing a suitable self-adaption phenomenon at the contact surface. The scope is twofold, (i) to increase the hardness and the capacity of the coatings to support increasing applied loads on the contact and, (ii) to allow the formation of perfect aligned TMD basal planes parallel to the surface, avoiding oxidation and guaranteeing very low friction in all atmospheres.

In this talk, we will present our approach that goes beyond the state-of-the-art, related to the deposition of alloyed-TMD coatings by sputtering techniques. By varying the deposition parameters, including the type and amount of alloying element, we intend to tailor the structure and microstructure of the coatings in order to allow a suitable self-adaption of the material in the surface contact, either promoting (re)crystallization of the material or the in depth reorientation of TMD crystals. With this procedure, friction coefficients as low as 0.03 and 0.005 are possible to be achieved in humid and dry atmospheres, respectively, under contact pressures higher than 1 GPa.

Keywords: self lubrication, low friction coatings, super low friction, sputtering

Biography:

Full Professor in the University of Coimbra, Portugal. In 1990, he received a PhD from Coimbra University on the field of Mechanical Engineering. His field of research and publications is very diversified as e.g. on materials and surface engineering, deposition and characterization of thin films, tribology, nanocrystalline/nanocomposite materials. He participated in more than 30 research projects (responsible in more than 20). He was invited for talks in about 30 international conferences on his field. He supervised 14 PhD students and has an extensive evaluating activity for national and international research agencies. He published more than 200 papers in international journals of SCI.

Tribo Chemistry

Chair: Sascha Louring

Tuesday 10 June 2014 - 14.20-15.20

Room: Suecia

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Study the lubrication behavior of chemical mechanical polishing (CMP) of highly boron-doped polysilicon at moderate and high polish velocities

Hamidreza Pirayesh, PhD student*, Dr. Ken Cadien, Professor

University of Alberta, Canada

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Chemical mechanical polishing is a critical step in microelectronic fabrication industry. It combines both chemical and mechanical forces to polish the semiconductor surface and form the global planarization. It has been shown that doping of polysilicon reduces the polish rate significantly. This is due to the retardation of chemical reactions on the semiconductor surface after doping boron. In this study we tried to improve the polish rate by studying the mechanical factors such as lubrication behavior during polishing. It is shown that the mechanical forces are dominant in boron-doped polysilicon polishing. We concluded that by reducing the slurry flow rate and increasing the polish velocity the lubrication regime alters from boundary to dry lubrication. Increasing the polish temperature and friction force proved that the lubrication and mechanical effects play the major role in this phenomenon. This helps improving the polish rate even though less slurry was consumed in the process. In this study we also developed a model explaining the interaction of chemical and mechanical forces to improve the polish rate. This model shows that the polish rate increases by improving the polish friction at a constant flow rate or velocity.

Keywords: lubrication, Boundary lubrication, Dry lubrication, Chemical mechanical polishing (CMP)

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Effect of normal load on multi-degradation mechanisms of super duplex stainless steel exposed to tribocorrosive-fatigue environment

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Passive metals exposed to wear and fatigue in corrosive environment may suffer from multi-degradation phenomena. It is not possible to approach the problem from the standpoint of tribology exclusively or corrosion and fatigue solely to make any theoretically or experimentally valid assessment of the damage, durability or limiting states of these passive alloys. Synergetic effects of this complex scenario result in drastic reduction in the lifetime of systems in which any failure leads not only to significant material losses, but puts people and eco-systems at risk. Board marine and offshore vessels and installations are one of the main places that passive metals are exposed to multi-degradation. They are typically involved in critical operations like mooring, material handling by cranes and hoisting systems, riser tensioning, heave compensation and rotation equipment during drilling.

The complex multi-degradation mechanism has been first studied and proposed by von der Ohe et al. with a first approach based on tribocorrosion experience and fatigue. However there is still a long way to go to investigate the causes and micromechanisms of this type of material degradation for proposing a model able to predict component failure and therefore for better designing structures.

In the present work, different types of stainless steels have been tested under multi-degradation conditions by means of in-house developed lab scale multi-degradation (LSMD) test rig. This rig provides 4-point static or cyclic (fatigue) bend testing while applying reciprocating rubbing on the tensile loaded side of the exposed test surface, in addition it includes arrangements for performing electrochemical measurements to simulate saltwater (3.4wt% NaCl) with presence of hydraulic fluids. Consequently samples are characterized and the mechanisms contribute in the processes of wear, corrosion and fatigue will be studied.

Keywords: multi-degradation, tribocorrosion, super duplex stainless steel, fatigue

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Neutron reflectometry of boundary films on DLC coatings

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Adsorption is one of the key phenomena involved in the boundary lubrication since it determines the formation and resistance of the boundary films. We used neutron reflectometry to study the adsorption ability of alcohols and fatty acids from PAO oil solution onto several DLC coatings (a-C, a-C:H, a-C:H:F and a-C:H:Si). We determined the thickness and the density of the adsorbed layers to reveal how the coating composition and doping elements affect the adsorption ability. The non-hydrogenated a-C coating proved to be the most inclined to adsorption, which is assumed to originate from the lack of hydrogen, which is a well known surface passivation source. On the other hand, no adsorption layers were detected on the F-doped DLC coating, which revealed the non-reactivity of the coating. To study the resistance of the adsorbed films, the surfaces with the adsorbed molecules were cleaned ultrasonically in heptane and analyzed by ToF-SIMS and XPS. We proved that the ultrasonic cleaning - irrespective of its duration - does not affect the amount of adsorbed molecules with respect to rinsing, which reveals the good resistivity of the adsorbed molecules to external influences. The obtained results show that the adsorption on DLC is possible and presents a potential boundary lubrication mechanism for DLC coatings despite their general non-reactivity.

Keywords: DLC, boundary films, adsorption, neutron reflectometry, alcohols, fatty acids.

Wear & Lubrication

Chair: Käti Valtonen

Tuesday 10 June 2014 - 14.20-15.20

Room: Dania

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The Failure and Damage Mechanisms under Friction of Copper in the EHL and Mixed EHL Regions

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Recently, friction and wear behavior of Copper (Cu)-steel pairs rubbed under different lubrication conditions were studied. The Stribeck curve was used to identify the different regimes of friction of copper with different virgin grain sizes the elasto-hydrodynamic lubrication (EHL), mixed lubrication (ML) and boundary lubrication (BL) regimes. The aim of this work is the detailed analysis of the damage evolution under friction in the EHL and mixed EHL regions. The effects of load on the friction and the wear and damage mechanisms have been studied. The surfaces of Cu samples before and after friction have been analyzed using SEM and AFM techniques as well as roughness and hardness measurements. It was shown that the mechanisms of damage and failure of Cu samples under friction in the EHL region are similar to the damage and failure mechanisms in Very High Cycle Fatigue. Friction in the EHL region is accompanied by initiation and coalescence of pores and microcracks. The effects of the coalescence of pores and microcracks observed in the EHL region are enlarged with a subsequent loading in the mixed EHL region. The effect of the loading rate on the transition from the EHL to BL region has been studied. It was shown that decreasing the loading rate increases significantly the load of the transition from the EHL to BL region. The pore and microcrack coalescence remain the dominant damage mechanism under friction in the mixed EHL region with the low loading rate while a lot of ploughing tracks, large delaminated regions appeared on the surface of Cu sample after friction with the higher loading rate.

Keywords: Friction, Copper, Stribeck curve, Failure, Damage

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Proposal of invariant precursor for boundary lubricated scuffing

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One of the fundamental problems in Tribology is the prediction of finale performances and particularly the longevity of lubricated frictional organs. In most cases the hydrodynamics, elastohydrodynamics lubricated parts if load is too high or displacement of rubbing bodies is too slow the boundary lubrication takes a place and prediction of performance becomes complicated because scuffing can appear [1,2]. The authors try to shear their knowledge and contribute to better understanding of that transitional phase dealing frequently with catastrophic wear. It can be the proposal one of new paradigm shift of today's Tribology [3,4]. The paper presents the analysis of various features allowing the identification of starting point to scuffing process. Authors present the topological paradigmatic approach to this problem in which the key role plays the interaction between rheological, morphological and physicochemical properties of contacting surface's layer [5]. For academic reasons specific tribological conditions are selected. The results of scuffing test of different burnishing finishing process conditions offering various ground surface properties in order to modify tribological wear performance of AISI 4130 cylinders-plane of ductile cast irons counter bodies boundary lubricated with gear oil (extreme pressure EP additives) are discussed [5]. The interface rheological behavior based on micro-hardness and morphology measurements allowed contact mechanics analysis in frame of plasticity index. Morphological investigations are consisted in the analysis of areal field, functional and features parameters. The physicochemical part of investigations was carried out on the basis of the residual stresses and wettability measurements with the surface free energy and its components calculations [6,7]. Critical analysis of interfacial parameters for steady (burnished cylinders) and transitional states up to the catastrophic wear (scuffed cylinders) is commented in order to establish universal laws of shift from stable wear under boundary conditions to scuffing.

Taking into consideration the topological approach, the mutual interactions between analyzed parameters in the context of scuffing were investigated and elucidated in order to propose invariant precursor concept.

Keywords: boundary lubrication, scuffing, topological approach

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Influence of Physical States of Amide Type Gel-Lubricants on Tribological and Rheological Properties

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Presenting author: Kazumi Sakai

Amide type Gel-Lubricant (Gel-Lube) is a unique lubricant since Gel-Lube looks grease (gel) at low temperature and changes to liquid at higher temperature. These physical state changes are repeatable. This characteristic feature is attributed to the composition of Gel-Lube. Gel-Lube consists of liquid lubricating oils and solid fatty amides. Fatty amides work as not only thickeners but also the oiliness agents. Therefore, the oiliness effect provides Gel-Lube with the low friction properties. Gel-Lube could be applied to various machinery lubrications for energy-saving.

Tribological properties of Gel-Lube compared with conventional oils and greases have been reported, for instance, friction properties under boundary lubrication conditions. However, the understanding of detailed tribological and rheological behaviors of Gel-Lube related to its physical state changes was not sufficient. Therefore, these properties focused on physical state changes of Gel-Lube depending on temperature were examined. As a result, liquid state Gel-Lube showed superior friction properties to gel state. It is suggested that rheological property changes of Gel-Lube play important roles in addition to the oiliness effect of fatty amides.

Keywords: tribology, rheology, gel-lubricant, low friction, lubricants

Modelling 1

Chair: Kenneth Holmberg

Tuesday 10 June 2014 - 14.20-15.20

Room: Nortvegia

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Atomistic origins of tribologically induced metallic surface folding

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Tribology as the science of the interaction of surfaces in relative motion has many important technological applications including machining, polishing and bearings. During tribological loading of metallic surfaces, mechanically driven material intermixing processes induce quite complex phenomena, such as plastic flow swirls that resemble Kelvin-Helmholtz instabilities or lamellar folding patterns, which lead to debris particles reminiscent of flaky pastry. Especially atomistic simulations can yield valuable insights into the evolution of surfaces because of the possibility of in situ analysis of the intermixing processes and topographical evolution. In this contribution, we will reveal the emerging patterns during shear deformation and surface generation on a nanocrystalline copper substrate by molecular dynamics simulations. Besides the interplay between dynamic recrystallization and grain growth, the disruption of laminar surface plastic flow and the formation of surface folds is observed. For this specific topic, we will show that the polycrystalline bulk structure induces anisotropic material flow behavior, depending on the crystallographic orientations of the grains. We demonstrate that folding can lead to layered structures that act as precursors to lamellar wear particles.

Keywords: Tribology, Folding, Nanocrystalline, Machining, Molecular Dynamics, Plastic Flow

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Combined consideration of qualitive and quantative factors in computer modeling of tribological systems

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**- presenting author*

Usually two main types of mathematical models are used for tribological systems. The first ones are analytic models formed on a basis of natural laws known in Physics, Mechanics, Chemistry and so on. The second ones are statistic models based on experiments realized either for the real objects or for some test benches. The both above approaches have significant difficulties when qualitative factors take place together with quantitative ones. However, such situation is usual for tribology. Soiling of contacting surfaces, shape of wear particulars, etc. often take an important part comparable with pressure, sliding velocity and so on.

In this paper system approach and combination of mathematical and computer simulation are used to get some hybrid model connecting controlled entrance factors and system response function. It's like as regression equation but real experiments are replaced on computer imitation and different ways of estimation of model adequateness and model parameters are used here. In proposed approach statistical models are replaced for fuzzy sets models. The general way of computer modeling is creation of tribological integrated expert systems. They have "intelligent" part based on artificial intelligence technologies and "traditional" part, which is developed by usual software development approaches. So, expert systems blocks are working here together with data bases and calculation modules. In general, proposed integrated expert system can be used as software supporting to make decisions regarding friction units design. It can also take part of subsystem for CAD/CAE system. An important component of the software work is information support. It's proposed to develop multilevel information model of tribological system.

Proposed approach is presented with an example of complicated tribological system including interaction between wheel and rail. The multilevel information model is formed as a result of analysis of a great amount of various information resources. A method of systematization of tribological knowledge is presented. The method is based on development of knowledge base as a set of production rules. Every rule has an universal structure including parts "IF", "THEN", "insurance factor". The last part is the fuzzy set belonging function value. Specific method of estimation of that factor is presented in this paper.

Proposed approach can be used for modeling of friction and wear in tribological systems. It can be used also within CAD/CAE systems for computer modeling of machines including friction units.

Keywords: tribological system, computer modeling, qualitative and quantitative factors, expert systems, information model

Machine Elements

Chair: Ronald Larsson

Tuesday 10 June 2014 - 15.40-17.00

Room: Suecia

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Rolling Contact Fatigue Of Hydrogen Infused Bearing Surfaces Under An Applied Hoop Stress And EHL Conditions

***Shravan Janakiraman*[1]*, *Ole West*[1], *Peder Klit*[1], *Niels Jensen*[1]**

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* *: Presenting author*

Rolling element bearings are used in the gear systems found in the gearbox of wind turbine drive-trains. The bearings are mounted on the shaft using a interference fit, thus imparting a hoop stress and radial stress to the bearing inner ring. High pressures and temperatures can be generated in the lubricant film between the non-conformal contacts of the roller and the inner ring. It has been suspected that, hydrogen, potentially from the lubricant diffuses into the bearing elements. It is however hard to verify the presence of hydrogen in the metal, because it diffuses out at room temperature. The presence of hydrogen increases the susceptibility of the bearing material to rolling contact fatigue failure.

Experimental conditions were created to closely resemble the mounting stresses and loading conditions as experienced in the field. Rolling contact fatigue tests were conducted, where two rings, simulating the non-conformal contact in the bearings, were run against each other with continuous lubricant supply at the contact at steady state. The regime of lubrication was Elastohydrodynamic lubrication (EHL). The rings were made from standard 100Cr6 SKF bearing steel,. The rings were immersed in a solution of Ammonium Thiocyanate for 48 hours to introduce hydrogen in them, before mounting. The rings were mounted on shafts with a conical interference fit. The rings were loaded against each other at high loads, corresponding to large maximum Hertzian contact stresses. There was minimal slip between the two rings in the contact zone. The experiments were conducted to study the mode of failure and number of cycles to failure for each ring pair tested. The number of cycles to failure for each ring pair was plotted on a Weibull graph.

The results indicated that the crack initiated near the surface. After the fatigue crack propagation a final brittle fracture occurred. The plane of fracture was perpendicular to the direction of the hoop stress. Surface pitting was observed in all the rings tested. The fracture mechanisms were compared to the fracture mechanisms observed in other hydrogen infused bearing surfaces, but not under the influence of any applied Hoop stress.

Keywords: elastohydrodynamic lubrication, fatigue, rolling contact fatigue, hoop stress, hydrogen infused surfaces

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On the Running-In Behaviour of Lubricated Line Contacts

Thomas Lohner [1] ***(Presenting Author), Josef Mayer*** [1]***, Klaus Michaelis*** [1]***, Bernd-Robert Höhn*** [1]***, Karsten Stahl*** [1]

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Running-in corresponds to a conditioning process of the contacting surfaces of rolling and sliding elements during the first operating hours and is usually associated with surface roughness smoothing. Thereby, the selected operating conditions are usually within the mixed lubrication regime in order to provoke asperity contact of the rough surfaces. As the running-in of machine elements can be seen as a transient tribological system, the surface topography is modified by wear and plastic deformation until a steady state condition is reached. This condition can be defined by a steady coefficient of friction or a steady wear rate. The running-in also strongly influences the formation of tribofilms, particularly if additive-containing lubricants are used. Therefore, a well-designed running-in procedure has large potential to increase the load carrying capacity and efficiency of machine elements without any effort in terms of element design.

The intention of this study is to offer further insights into the running-in behaviour of lubricated line contacts in discs and gears (both made from case-carburized steel and cross ground) with particular attention to the correlation between running-in parameters, surface roughness, pre-damages and measureable parameters during running-in time. Thereby, experimental investigations are performed at a model test rig (FZG twin-disc machine) and at a gear test rig (FZG back-to-back test rig). Parameter variations include the initial surface roughness, lubricant additive and the lubricating condition defined by the applied load, oil temperature and circumferential speed.

The work packages are as follows: First, running-in experiments are performed at a twin-disc test rig characterized by simple test part geometry and excellent reproducibility. Second, the results obtained from the twin-disc-machine are transferred to the path of contact of the specified test gears by a local analysis in order to define different running-in conditions for test gears. Thereby, a specific parameter is introduced to describe the relative surface loading during running-in. Third, extensive experiments are performed at the FZG efficiency back-to-back test rig in order to have the possibility to measure the mean coefficient of friction during running-in time. For each running-in for discs and gears, the friction coefficient, the surface roughness and the close-surface material condition is properly investigated. For the twin-disc experiments, additionally the bulk temperature of the discs is measured.

Results show that the additive package has major influence on the solid state friction coefficient, on the characteristics of touching surface asperities, on the tribofilm formation and therefore on the entire running-in process. The applied load has the most significant influence on surface roughness reduction. Besides very limited “micro-cracks” on the surface, no clear pre-damages are found for any parameter configuration on discs after running-in. For gears, when load is increased above a critical level, clear pre-damages characterised by cracks, micropitting and profile deviations are identified. Depending on the running-in condition, significant advantages in terms of gear efficiency and in terms of the scuffing load carrying capacity of gears are found.

Keywords: running-in, mixed-lubrication, asperity contact, tribofilm formation

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In situ surface characterization of running-in of involute gears

***MSc. Mario J. Sosa*, Dr. Stefan Björklund, Dr. Ulf Sellgren, Prof. Ulf Olofsson**

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Gear life and operation are in large part determined by the properties of the contacting surfaces, and these inevitably change over its life. The initial topography transformation, often referred to as running-in, is of pronounced importance. The focus of this paper is how running-in of the surface topography can be characterized and also what methodology can be used to characterize it. To characterize running-in gears were run in a FZG back-to back-test rig utilizing a Form Talysurf Intra in situ. This enables the system to stay unchanged, and as well as permitting the same gear tooth surface to be measured and with enough precision to study the same surface at different stages. The separation of roughness from the form and waviness has been achieved through surface roughness measurement. The gear tooth surface was measured as manufactured, after a standard running-in procedure, and after different operational conditions, varying load, speed and temperature. Running-in is characterized both qualitatively by plotting of roughness profiles, and quantitatively by analyzing a selected set of roughness. Conclusions from this paper show that the summits of the asperities were worn off at the initial running-in stage; roughness, waviness and form can be separated utilizing a carefully chosen polynomial fit and a Gaussian filter; surface topography can be studied initially, after running-in, and after operation in situ; and complete wear of the initial surface can be demonstrated in some circumstances.

Keywords: gear, running-in, surface topography

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A study on surface influence on gear efficiency and lubricant temperature

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Losses in a vehicle gearbox influence the fuel consumption. These losses can be divided in to load dependent and speed dependent losses and they occur in the gears, bearings, seals and auxiliaries such as pumps. One way of reducing the speed dependent losses in gearboxes is to lower the lubricant level. In this way the amount of oil that is splashed around by the gears and bearings dipping in to the oil is reduced. On the other hand, a certain amount of oil is necessary to dissipate heat away from the contact. Furthermore oil is necessary for the transport of additives to build up a protective tribo layer between the contacting gears.

In this study the energy losses in a gearbox are measured together with lubricant and gear temperature to study the influence of initial gear surface roughness and PVD coated gear surfaces in parallel with different oil levels in the gearbox. The tests were performed in a back-to-back gear test rig, in this case an FZG efficiency test rig, modified to measure the temperature of the contacting gear pairs. Gears with different surface manufacturing methods, grinded and polished, as well as coatings on the polished gears were tested against each other. Lubricant temperature, gear bulk temperature and torque loss was measured for a set of speeds and lubricant levels while the contact pressure was kept constant.

The load and speed dependent losses for the gears are obtained for the different test conditions by using analytical expressions for the losses in seals and bearings together with the measured torque loss.

The main findings for all lubricant levels are that a higher efficiency in the gear contact is obtained both for smoother and coated gears, as well as a slightly lower lubricant and gear temperature. As expected, speed dependent losses are significantly reduced with a lower lubricant level while the load dependent losses increase with a lower level. Thus, the results indicate that it is possible to find an optimal lubricant level for a given degree of surface roughness that minimizes the losses while fulfilling the need of lubrication and cooling.

Keywords: gears, efficiency, temperature

Texturing

Chair: Klaus Pagh Almtoft

Tuesday 10 June 2014 - 15.40-17.00

Room: Dania

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Effect of counterface roughness on adhesion of mushroom-shaped microstructure

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To elucidate the effect of the substrate roughness on adhesion of mushroom-shaped microstructure, we have replicated topography of 12 different surfaces and, using replicas made of the same material, measured pull-off forces of microstructured and smooth samples. It was found that classical roughness parameters, such as average roughness Ra and others, cannot be utilized to explain topography-related variation in pull-off force. This has led us to the development of an integrated roughness parameter capable of explaining results of pull-off measurements. Using this parameter, we have also found that there is a critical roughness, above which neither smooth, nor microstructured surface could generate any attachment force, which may have important implications on design of both adhesive and anti-adhesive surfaces.

Keywords: biomimetic, fibrillar adhesives, pull-off force, surface topography

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The effect of oil pockets array on tribological behaviour of sliding elements

Slawomir Wos[1], Waldemar Koszela[1] and Pawel Pawlus[1*]

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The introduction of specific textures on sliding surfaces, including micropits (or holes, dimples, cavities, oil pockets) is an approach to improve the seizure resistance of sliding elements. Those micropits may reduce friction by acting as a reservoir for lubricant, improving seizure resistance. Holes can also serve as a micro-trap for wear debris in lubricated or dry sliding. Various techniques can be employed for surface texturing including machining, ion beam texturing, etching techniques and laser texturing. Surface texturing has been shown to provide tribological benefits in terms of friction reduction in conformal contact. A lot of experiments were done using pin-on-disc testers. On the basis of literature review it is possible to select parameters of textured surfaces like pit-area ratio (oil pockets density), dimple depth, width and surface roughness in areas free of dimples. However the effect of oil pockets array (layout) on tribological behavior of sliding elements has not been explained yet. It is usually selected based on intuition of researchers.

In this work the attempt was done in order to explain mechanism of influence of selected oil pockets array on tribological properties of contacting elements. Experiments were carried out using pin-on-disc tester in conformal lubricated contact for different sliding speeds. Surface texturing was done using abrasive jet machining with application of laser cut mask. In order to eliminate the effect of different input variables, in all the experiments pit-area ratio and sizes of oil pockets were very similar. Five types of oil pockets arrays were tested:

- radial,
- concentric,
- spiral,
- of square arrangement,
- of random arrangement.

The experiments were also made for untextured polished disc. During tests the friction force was monitored as a function of time. Before and after tests, disc surface topography was measured using a white light interferometer Talysurf CCI Lite with 0.01 nm height resolution.

The beneficial effect of surface texturing was obtained for spiral array of dimples on disc surface. The presence of radial array of oil pockets resulted in the worst tribological properties of tribological assemblies containing textured discs.

Keywords: textured surfaces, pin-on-disc, friction force

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Application of fractal analysis to diagnose contact interaction of frictional solid objects

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The additional quantitative research tools are developed to examine the surface roughness: the fractal dimension of bearing surface curvature and the fractal dimension of profilograms. These values are used to classify the contact interaction modes of the frictional metal elements and to diagnose the type of contact according to the fractal dimension scale by describing the main three types of contacts: elastic, elastic-plastic, plastic.

Keywords: friction, roughness, bearing surface curvature, fractal analysis, diagnostics, contact interaction mode

Modelling 2

Chair: Ulf Olofsson

Tuesday 10 June 2014 - 15.40-17.00

Room: Nortvegia

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Simulation of a Hydraulic Rod Seal with a Micro-Patterned Rod

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A numerical model of a hydraulic rod seal operating with a micro-patterned rod has been constructed to determine if such a rod can reduce seal friction without increasing leakage.

The motivation for this work is the high friction forces measured on the rod and seal by manufacturers, and the fact that micro-patterned surfaces have been successfully applied to other machine elements like journal bearings, piston rings and mechanical seals to reduce friction.

The numerical model is comprised of a fluid mechanics analysis of the flow through the fluid film, a contact mechanics analysis, and a deformation analysis of the seal. These three components are coupled so an iterative computational procedure is used.

The finite element analysis for the static contact mechanics and static deformation has been the greatest challenge in this project. While the maximum axial width of the sealing zone is about 2.5 mm and the rod diameter is 44 mm, the characteristic dimensions of the triangles are in the 5 to 80 micron range. So a very fine mesh near the sealing surface must be used. Therefore, for a complete 3D model of this seal one would need about 10^9 elements. This is a huge number, when compared to the 10^4 elements typically used for a 2D model. So it is clear such a 3D model is not practical.

In the present study a new unique FEA approach for the static contact and static deformation analyses has been developed. It is based on the fact that the material in the seal lip above 100 microns from the sealing surface is unaffected by the rod surface features, like micro-cavities. Therefore, a 3D FEA is performed on a model of only the lower layer of lip material, divided into 6 axial segments. The displacement boundary condition on the upper boundary of the layer is obtained from an axisymmetric 2D FEA of the entire seal with a smooth rod. The 3D models of the 6 segments are used to compute the static contact pressure distribution and the static deformation.

The above numerical model has been used to generate friction and leakage data over a range of operating speeds.

Keywords: hydraulic seal, rod seal, reciprocating seal, micro-pattern.

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Roughness Evolution in Mixed Lubrication Condition due to Mild Wear

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Modelling of surface roughness evolution in time, as a function of the lubrication condition and other operating parameters (i.e. load, sliding/rolling ratio, and initial roughness of both contacting surfaces) is very important for understanding and prediction of various surface damage modes, such as surface distress, wear, and scuffing. Moreover, it is one of the key points in understanding friction and running-in phenomena.

In the present study, a previously developed model for partial micro-elastohydrodynamic lubrication conditions is combined it with a local Archard-type wear model to describe the surface topography evolution during the operation of a rolling/sliding lubricated contact.

The model has been compared with a series of experimental results showing good agreement.

Keywords: surface roughness, mild wear, running-in, mixed lubrication.

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Model for Contact Area between Finger and Sinusoidal Plane to Evaluate Adhesion and Deformation Component of Friction

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One of the main parameters affecting finger friction, friction induced vibrations in the finger and consequently tactility is surface topography. Different peaks, amplitudes and spatial distributions affect for example contact area and adhesion forces, the deformation and generated vibrations into the finger.

Earlier Skedung et.al. made subjective tests and objective finger friction measurements on fine controlled surfaces. These surfaces were sinusoidal with a wavelength between 0.27 and 98.8 µm and amplitude between 0.007 and 6 µm. To examine the variations in friction an analytical model that calculated the contact ratio for one finger ridge was used. This model showed a correlation between the contact ratio and the friction coefficient.

Expanding this model to cover the whole contact area together with the adhesion and deformation component of friction would give further understanding of the contact between the finger and rough surfaces. The finger print is modelled as trapezoid shaped ridges in a circle formation and the test surface as a sinusoidal plane. With data for the different surfaces and normal forces can the deformations and contact area be calculated which give the adhesion and deformation component of friction force.

Furthermore, this model can be used to see how the different surface parameters influence the friction and also estimate the level of friction before manufacturing of a surface.

Keywords: finger friction, model, real contact area, adhesion, deformation.

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Theoretical Analysis of the Local Load Situation of Rough Surfaces

Jun.Prof. Dr.-Ing. Balázs Magyar, Prof. Dr.-Ing. Bernd Sauer

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The real contact conditions of machine elements influence their life time. The modern simulation techniques can be help to understand the fatigue mechanism, started from the surface region of machine elements. Based on such numerical solutions the rough surface topography can be optimized.

This paper will present a complex calculation method to determine the local load situation in the dry contact of rough surfaces. First of all the generation method of rough surfaces and their analysis are presented. In the next step the calculation of the contact pressure and the deformation on the basis of the half space theory and the finite difference method are described. Taking into account of the calculated contact pressure distribution the sub surface stresses and the three dimensional temperature distributions also can be computed. The first based also on the half space theory and the second on the numerical solution of the differential equation of the heat conduction. After this analysis the mechanical and thermal load situation in the contact is known.

Finally a parameter study shows the effect of the load on the pressure, stress and temperature distribution.

Keywords: generation of rough surface, contact calculation, temperature calculation, stress under the surface

PLENARY SESSION 2

Wednesday 11 June 2014 - 08.40-09.20

Professor Martin Priest

Chair: Svend Stensig Eskildsen

Friction and Durability of the Piston/Cylinder Interface in Reciprocating Engines

Martin Priest

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Abstract:

The tribology of the reciprocating piston in an engine is crucial to its overall performance as the interface it forms with the cylinder wall is the largest source of friction power loss in an engine, has a high potential for wear and strict control of lubricant flow in this region is essential for limiting oil consumption and unwanted exhaust emissions. Recent advances in engine hardware to increase powertrain efficiency have exposed the piston, the piston rings and the cylinder wall to more extreme operating conditions and made the control of friction and wear ever more difficult. Furthermore, the lubricant in this region is subjected to high levels of contamination by fuel (including bio-fuel components), water and combustion products and is degraded at the elevated local temperatures, primarily by oxidation and nitration.

This presentation will provide a review of a large body of experimental research by the author and co-workers into the tribology of this crucial sub-system of the engine. A specific single cylinder gasoline research engine, of modular design but importantly using a standard commercial piston and piston rings, was chosen to provide a consistent, accessible and realistic environment to study the tribology and its response to changing operating conditions and the degradation of the engine lubricant with time. Results for lubricant film thickness, lubricant degradation, lubricant flow, friction and wear have been obtained for a wide range of lubricant and fuel formulations. Greater insight has been gained into the tribology of the piston/cylinder interface and how it evolves as the lubricant ages. The results also provide a comprehensive data set to validate and enhance mathematical models for the tribology of the piston, piston rings and cylinder wall.

Biography:

Jost Professor of Engineering Tribology at the University of Leeds and Chairman of the Leeds contribution to the Leeds-Lyon Symposium on Tribology, now in its 41st year. He is associate editor of the journal Tribology Transactions and an editorial board member for several other journals in the field. His research interests encompass fundamental studies of lubrication, friction and wear; application of tribology to the lifecycle of engineering systems and the tribology of internal combustion engines.

Keywords: film thickness, lubricant, degradation, tribology, wear

Abrasion

Chair: Jørgen Jakobsen

Wednesday 11 June 2014 - 09.40-11.20

Room: Suecia

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Erosive and abrasive wear resistance of carbide free bainitic steels

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Steels with fine ferritic-austenitic lath microstructure with high strength and toughness have also shown to have good sliding and sliding-rolling wear resistance. In this work has one of these so called carbide free bainitic (CFB) steels been tested in two heat treated conditions and compared with currently used quench and temper (QT) steel in an industrial application subjected to a complex mixture of erosion- and abrasion-wear in combination with impact resistance. In addition have these steels been subjected to abrasive laboratory test.

The wear resistance has been determined by the specific wear rate for the laboratory tested samples and by measuring the volume and weight losses in the field tests. The microstructural changes in the steels have been investigated by optical- and scanning electron-microscopy. The hardness and hardness changes of the different steels have been investigated.

The results show that the abrasive wear rate of the CFB steel is up to 50 % lower in comparison to the QT steel in the laboratory tests. The field tests show that the volume and weight loss of the CFB steel in the 2 tested conditions is less than 10 % in comparison with that of the currently used QT steel. The improved wear resistance of the CFB steel can be explained by the higher hardness and higher increase of the hardness in the surface layer of the CFB steel.

Keywords: carbide free bainite, erosion, abrasion, wear resistance

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Influence of hardness and microstructure on the mechanisms of deformation and wear of cemented carbides for rock drilling

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[2]Materials Science, Dalarna University, Sweden

The combination of high toughness and high hardness makes cemented carbides the most widely used material for the rock crushing parts of rock drills. As indicated by the name, cemented carbides are composites, most often comprising tungsten carbide grains cemented together by a cobalt binder phase. This combination of a hard ceramic phase in a ductile metallic binder phase makes the material hard enough to avoid excessive deformation against the rock, while also being tough enough to minimise brittle fracture. These mechanical properties often result in low wear rates and wear mechanisms that operate on a very small scale. The properties can be fine tuned by adjusting two main parameters, the grain size of the hard phase and the fraction of ductile binder. Additionally, the binder phase material as well as the carbide material can be varied.

The present investigation employs a newly developed laboratory technique to study the influence from the microstructure of the cemented carbide on the mechanisms of its deformation against a scratching rock tip. The selected microstructures include two cemented carbide grades that are commonly used in rock drilling but also grades spanning a much wider interval of carbide sizes and binder fraction. Moreover, cemented carbides including alternative binder phases are used for comparison. This wide range of cemented carbides is used to gain fundamental insights into the relations between microstructure and micro-scale deformation and wear, in contact with rock materials.

The initial micro-scale deformation of polished cemented carbide surfaces is studied by micro scratching with rock materials tips, nano scratching with diamond tips, and also by instrumented nano indentation (hardness testing). The deformation is evaluated on the submicrometer scale using high resolution FEG-SEM with EBSD, FIB cross sectioning and AFM. The results are discussed with respect to their significance for wear of cemented carbides in rock drilling operations.

Keywords: cemented carbides, microstructure, scratching, deformation, wear, rock drilling

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Abrasive wear of CVD α-Al_2O_3 and Ti(C,N) coatings at room and elevated temperature

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Abstract

In the present study the wear resistance of three CVD α-Al_2O_3 coatings with different growth textures, i.e. (001), (100) and (012), and a CVD Ti(C,N) coating were investigated by using micro abrasion test and high temperature pin-on-disc test, respectively. Micro cutting and micro chipping were found to be the dominant wear mechanisms and the latter does strongly control the wear rate of the coatings. Also, differences in superficial plastic deformation and adhesive wear have an influence. Of the three Al_2O_3 coatings the (001) texture shows the best wear resistance in micro abrasion test using small abrasives at room temperature (RT) and in the pin-on-disc test at both RT and 450°C. In general the Ti(C,N) shows a better wear resistance, due to its higher hardness, as compared to the Al_2O_3. The results obtained are discussed in relation to the dominant wear mechanisms of the coatings identified using scanning electron microscopy.

Keywords: abrasive wear, CVD coating, elevated temperature, Al_2O_3, coatings texture

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Nanotribological simulations of multi-grit polishing and grinding

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**presenting author*

A quantitative molecular dynamics (MD) study of nanoscopic wear under dry grinding and polishing conditions with multiple abrasive grits is presented. The initial topography of the monocrystalline iron surface has a pseudo-random Gaussian height distribution, and the sixteen rigid abrasive grits have cuboid or spherical geometries. The grinding and the polishing process are differentiated via the kinematic constraints imposed on the abrasive grits. A post-processing scheme based on advection velocity dynamically identifies atoms as either part of a wear particle, the substrate, or the sheared zone between the two. The knowledge of each atom's zone affiliation and a time-resolved grid-based evaluation of the substrate topography lead to a break-down of the asperity volume reduction into its constituents: pit fill-up volume, individual wear particles, shear zone, and sub-surface substrate compression. The time and pressure dependence of the wear volume contributions as well as the roughness parameter Sq and the surface levelling are presented for selected systems.

Keywords: molecular dynamics simulations, abrasion, atomistic wear

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Microstructure refinement effect on two-body abrasion resistance of white cast irons

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In this study, the effect of microstructure refinement on the wear of white cast iron was investigated. Abrasive wear tests using a pin on garnet paper (whit mean size between 60 mm and 66 mm and hardness of 1453±85 HV) configuration were carry out employing a PLINT TE 79 machine at a normal load of 4.6 N as prescribed in the ASTM G132 standard.
In order to create a temperature gradient effect, the samples were melted placing a metal plate at the bottom of the sand mold. Subsequently abrasive wear samples of 3 mm diameter were cut (using wire electro-discharge machining.) at three different heights from the chill thereby obtaining four levels of refinement; with the following mean free path: 6.6±1, 15.2±2, 22.9±3 and 27.3±3 μm and with a constant carbide volume fraction about 22 percent.
Further microstructural characterization was performed by optical microscopy and X-ray diffraction (XRD). After wear tests the worn surfaces were examined by scanning electron microscope (SEM) in order to identify the wear mechanisms.

The results show that the mass loss increases linearly whit the increase in mean free path until the critical mean free path (about 23 μm). After the critical mean free path is reached, the rate of mass loss of the WCI increases at a lower linear rate. Finally, the study led to the conclusion that there is a special condition in which a particular abrasive size is critical value for a space between solidification carbides and this condition is dependent on the abrasive grain size.

Keywords: abrasive wear; microstructure refinement, white cast iron; second phase material.

IC Engine

Chair: Svend Stensig Eskildsen

Wednesday 11 June 2014 – 09.40-11.00

Room: Dania

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Experimental Investigation of the Tribological Behaviour of Cylinder Liner – Piston Ring Contact with High Pressure Difference Across Ring Pack

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[2] *MAN Diesel & Turbo SE, Teglholmsgade 41, 2450 København SV*

Abstract

The tribological interface between piston rings and the cylinder liner is a highly complex system. In order to study isolated effects a test rig was used and equipped with sensors. Experiments with varying running speeds, loading and geometry of the piston ring segment are conducted. The test rig is a scale model of a real engine. The cylinder liner – piston ring contact is studied in the test apparatus where the cylinder diameter is Ø160mm. The test apparatus consists of a frame structure in which cylinder liner, piston, piston rings and connecting rod from a L16/24 MAN engine is utilized. The piston has been modified such that up to four piston rings can be mounted in the piston. The pressure drop across rings is obtained by injecting high pressure air between the rings. The maximum injecting pressure is 60bar. The operation of the device is made using a crank mechanism in order to ensure engine-like operation. The frictional force between the liner and the piston rings is recorded. Furthermore sensors for evaluation of oil film thickness are installed.

Keywords: piston ring, friction, lubrication, experiment

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The lubricity of diethyl ether (DEE)

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**Presenting and corresponding author.*

Dimethyl Ether is known as a green fuel capable of giving high efficiency to diesel engines without forming particulate matter in the exhaust. While the combustion qualities of this fuel are excellent, its low lubricity and viscosity cause the fuel injection equipment to break down prematurely due to wear. A minor drawback is the low boiling point of the fuel which implies pressurisation to obtain a liquid.

The Medium Frequency Pressurised Reciprocating Rig (MFPRR) has been developed to establish the lubricity of DME [1]. As mentioned above the lubricity is very low but it can be redressed by commercial lubricity additives in moderate proportions, below 1000 ppm.

Diethyl Ether (DEE) is also an excellent fuel for diesel engines. It is an important part of arising diesel fuels so its lubricity property becomes important. The lubricity of neat DEE is of the same order as that of DME but it only responses very weakly to the addition of lubricity additives. Commercial additives in proportions of 5000 ppm do not even increase the lubricity to the kerosene level.

A number of liquid and solid additives have been mixed to DEE and after many trials an acceptable lubricity level has been reached. It was not foreseen that DEE would present more serious lubricity issues than DME the molecule being larger and thereby offering a better separation of the surfaces.

1. Sivebaek, I.M., Sorenson S.C. “Dimethyl Ether (DME) – Assessment of Lubricity Using the Medium Frequency Pressurised Reciprocating Rig Version 2 (MFPRR2).” SAE* Paper 2000-01-2970. 2000.

Keywords: Diethyl Ether (DEE), Dimethyl Ether (DME), lubricity, additives

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Testing scuffing resistance of materials for marine 2-stroke engines – Difficulties with lab scale testing of a complex phenomenon

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 # Combustion Chamber Parts, R&D, MAN Diesel & Turbo, Teglholmsgade 41, 2450 Copenhagen, Denmark

How can a complex phenomenon that is not well understood be tested? Scuffing in the cylinders of engines is a catastrophic type of wear that has been quite investigated through the years. However, there is still no agreement on what the mechanisms behind scuffing are. The catastrophic nature of scuffing implies a very high wear rate, which means that the cylinder liner has to be changed, and this is costly. The incentives for optimising the sliding materials and lubricating oil to reduce the risk for scuffing are therefore large. Especially, development towards higher power output and cleaner fuel aggravates the tribological situation, leading to higher risk for scuffing if no counteractions are made.

Here, experiences of scuffing in marine two-stroke engines are presented. These are accompanied by results from simple lab tests aimed for testing scuffing resistance of piston ring materials, to highlight the inherent difficulties of simulating the scuffing process in a lab test. The materials tested were grey iron and a plasma sprayed cermet coating, both used in engines today. In different tests, the tribological situation was aggravated by simulating starved lubrication and stepwise load increase, respectively. The influence of different appearances of the sliding surfaces on the scuffing resistance is also presented.

The ranking of the materials differed between the different types of tests and also between the tests and the experiences from real engines. The possible mechanisms between these differences are discussed. Further, mechanisms for avoiding scuffing as well as for initiating scuffing in different tests and in the engine are discussed and compared. Special emphasis is given to the different roles of the contacting materials, their surface topographies and their propensity to retain a small lubricant volume active in the contact.

Keywords: scuffing resistance, cylinder, piston ring, materials, marine two-stroke engine

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Investigation on friction properties of nickel ceramic electrodeposits

***Io Mizushima*[1], *Per Møller*[2] *and Anette Alsted Rasmussen*[1]**

[1]*IPU, Denmark*
[2]*Technical University of Denmark, Denmark*

Low friction engine coating has been demanded for reducing CO_2, NO_x and other emissions from combustion engines and increasing fuel efficiency of vehicles. Reduction of friction taking place between piston, piston ring and cylinder is critical, as more than half of the vehicle power loss is related to the friction.
Nickel ceramic coating based upon silicon carbide for internal cylinder walls has been popular for 40 years, since the coatings have good properties for immobilising an oil film on the cylinder wall causing lower friction, giving better wear resistance against adhesive wear and lower fuel consumption. More knowledge about functions of the ceramic particles in low friction coating combined with self-lubricating particles can contribute to reduction of energy consumption.
In this work friction properties and oil affinity of nickel co-electrodeposits containing different particles such as SiC, BN, CaF_2 and diamond were investigated. The oil affinity was evaluated with measurement of the contact angle of the engine oil to the deposits. Friction measurement was performed with a tribometer (CSM Instruments SA) both in air and in engine oil. Wear resistance was estimated with profile measurement of worn samples after friction measurement.
The Ni-ceramic coatings have similar property with respect to hardness. The friction coefficient in air of the Ni-SiC coating is higher than the ones of all other coatings, even higher than the one of pure Ni. The wear resistance upon the dry friction measurement of the Ni-SiC is a little worse than the one of the Ni coating. BN has a lower friction coefficient, but less wear resistance than the Ni-SiC coating has. The Ni-diamond coating has the lowest friction coefficient and the best wear resistance. The co-deposits have better oil affinity and a lower friction coefficient in engine oil than the pure nickel has. Especially BN has a good oil affinity. The wear resistance of the co-deposits upon the tribometer test in oil is higher. The particles are likely to work for improvement of lubricant property and besides CaF_2 and diamond can improve wear resistance of deposits.

Keywords: cylinder wall coating, friction, wear, lubricant, oil affinity

Adhesion & Friction

Chair: Janne Juoksukangas

Wednesday 11 June 2014 – 09.40-11.00

Room: Nortvegia

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Integrated surface chemistry and roughness characterization to study wetting and adhesion behavior

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1. Introduction

Wetting and adhesion behavior needs to be optimized in many applications. Wettability is usually studied by measuring contact angles using the well-known Young equation.

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} cos\theta_e \qquad (1)$$

The interfacial tensions, γ_{sv}, γ_{sl} and γ_{lv}, form the equilibrium contact angle θ_e of wetting. The Young equation assumes that the surface is chemically homogenous and topographically smooth. This is however not true in the case of real surfaces, which instead of having one equilibrium contact angle value exhibit range of contact angles. To define the equilibrium value, surface roughness should be taken into account. Relationship between surface roughness and wettability was defined by Wenzel who stated that adding surface roughness will enhance the chemical wettability of the surface [1].
Until now, it has not been possible to directly combine the surface roughness and contact angle measurements. Here we describe the equipment where these two measurements can be done together. In addition, example measurements will demonstrate the importance of separating the effect of surface chemistry and surface roughness.

2. Measurement principle

In the presented instrument, an optical tensiometer is integrated with an optical topography module. This enables measurement of the surface roughness on the same sample spot as the following contact angle measurement. Roughness measurement is based on the principle of fringe projection phase shifting in which a structure illumination pattern of sinusoidal intensity is projected on a surface. 3D contours of the surface modulate the phase of the fringe pattern seen from the camera's point of view. By calculating the phase shift caused by this modulation the 3D shape of the surface can be determined [2]. With this topography module it is possible to measure the 2D roughness parameters, such as R_q root-mean-square roughness but also its 3D equivalents S_q. The software will automatically measure the contact angle in the same area and calculate the surface roughness corrected contact angle values.

3. Conclusions

Measuring surface roughness together with the contact angle makes it possible to separate the influence of the surface chemistry and the surface roughness on wetting and adhesion behavior. This is especially important when working with different types of surface modifications where both surface chemistry and surface topography are altered. This abstract presents for the first time, integrated surface roughness and optical tensiometer equipment which enables the measurements to be done on the same sample location.

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The effect of surface roughness and carbon coatings on the friction performance in rolling contact

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Optimizing the friction and wear performance of high-load contact surfaces improves efficiency and provides longer lifetime for different applications. All of these lead to cost reductions and improved competitiveness. In this study the friction and wear performance in the rolling contact situation was studied by using the twin disc test device.

In Twin Disc tests a set surface finishing procedures providing different surface roughness values on test discs were evaluated with two different types of surface coatings. The surface finish grades represented the ground surface, and two polishing procedures providing surface roughness values of Ra 0.615 µm, 0.128 µm and 0.030 µm in average. The surface coatings were two carbon based coatings with a thickness of 1 to 2 µm. The Twin Disc test parameters were selected to represent the contact parameters in the gear contact. The contact load was increased stepwise in a similar way to FZG tests. The maximum contact pressure applied was 1.7 GPa and the surface velocities of the discs 1.05 m/s and 1.5 m/s for the upper and lower disc, respectively. The slide-to roll-ratio was thus about 30 %. The friction was measured during the tests and the wear performance of the discs was evaluated after the tests. Optical microscopy, scanning electron microscopy, nanoindentation and 3D profilometry were used for contact surface characterization.

The test results showed that high surface roughness induced micropitting of uncoated contact surfaces. With polished surfaces no micropitting or severe wear for the uncoated contact surfaces were observed. Hard carbon containing coatings deposited on rough surfaces were delaminated when high loads were applied on the contact. On the other hand, on polished surfaces the carbon containing coatings improved the wear performance and load carrying capacity compared to uncoated case.

The surface roughness had the major effect on friction performance, since the friction reduction in the range 11 to 18 % was provided by the smoother surface finish. Also the use of carbon containing surface coatings reduced friction by 1 to 10 % depending on the roughness of the surface.

Keywords: rolling contact, surface roughness, carbon coatings, friction

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Integrated characterisation and functional testing of friction-locking surfaces

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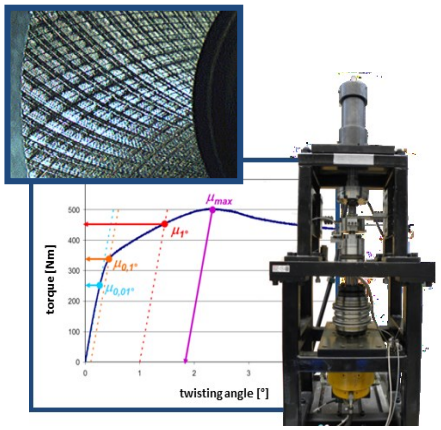
Frictional engaged surfaces can be found in several powertrain applications. At the dimension equations of bolt, shrink-fitted and flange joints the static friction coefficient acts as a linear actuating variable. Low Scatter of friction and a high static friction coefficient are functional requirements for a secure force transmission at friction locking surfaces. At the same time the technical specification of frictional surfaces is rarely function-oriented.

In this study, the friction locking material pairs are characterized with respect to surface geometry as well as material microstructure and boundary layer. The frictional properties of conventional, uncoated (milled, grinded and turned) surfaces were characterized under torsional and lateral force loading. Based on these results a methodological approach for the characterisation of friction characteristics and the definition of the static friction coefficient will be presented. The adhesion model developed by Kragelski was used and evaluated in order to investigate the adhesion of the specimen materials.



Furthermore the potential of friction enhancing surface modifications (e.g. laser structuring and PVD coatings) were investigated experimentally under static and dynamic load regimes. Reassembly of the friction surfaces and the influence of intermediate medium were also considered. Observed differences among the results are discussed and design guidelines for the engineering design process will be enunciated.

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- *Berger, L.-M.; Spatzier, J.; Gräfensteiner, M.; Vidner, J.; Leidich, E.; Schiefer, S.; Gröger, S.; Gerlach, M.: Investigation of HVOF-Sprayed Hardmetal Coatings for Static Friction Applications. Proceedings of the International Thermal Spray Conference 2013, Busan, Republic of Korea, 13-15 May 2013*

Keywords: static coefficient of friction, frictional engaged joints, friction enhancing surface modifications

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Friction property of DLC films in low-pressured hydrogen condition

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Diamond-like Carbon (DLC) film is a thin film of amorphous carbon which has sp2 and sp3 hybrid orbital. It is expected to be applied in various industrial applications because of their excellent tribological properties. Previous works showed that extremely low friction coefficient appeared in the case that hydrogenated DLC film pairs were slid in hydrogenated condition. However, the detailed mechanisms of the extremely low friction have not been clarified yet. In this study, the effects of surrounding hydrogen gas for the friction behavior of DLC films were investigated by varying the hydrogen pressure during friction tests.

Friction tests were carried out using the ball-on-disk tribotester which could change the test environment. The test conditions were at a load of 2.5 N, a rotation radius of 5 mm and a rotation speed of 6 rpm. The hydrogen pressure was varied with increment of 0.5 kPa from 0.5 kPa to 5.0 kPa every three minutes. After the hydrogen pressure reached 5.0 kPa, it was varied with decrement of 0.5 kPa to 0.5 kPa every three minutes. The test specimens were steel disks (ϕ24 mm × t7.9 mm, ISO100Cr6) and balls (ϕ4 mm, ISO100Cr6) covered with DLC films, respectively. The coating methods were CVD and PVD. The hydrogen contents of the CVD-DLC and the PVD-DLC were 30 at.% and free, respectively. The combinations of specimens were CVD-DLC / CVD-DLC and PVD-DLC / PVD-DLC.

The relationship of the hydrogen pressures and average friction coefficients was shown in Fig.1. The results of PVD-DLC tests in Fig. 1(a) showed that the average friction coefficients changed linearly with the varying of the hydrogen pressure. In the case of CVD-DLC in Fig 1(b), extremely low friction coefficient less than 0.01 was observed when the hydrogen pressure reached at 5.0 kPa. In addition, the hysteresis was shown in the relationship between the friction coefficients and the hydrogen pressure. From these results, it is considered that hydrogen contents of the DLC films and varying of the ambient hydrogen pressure influenced the specific decreasing of the friction coefficients. Further investigation using chemical analysis will be performed to clarify the mechanisms of the low friction phenomena.

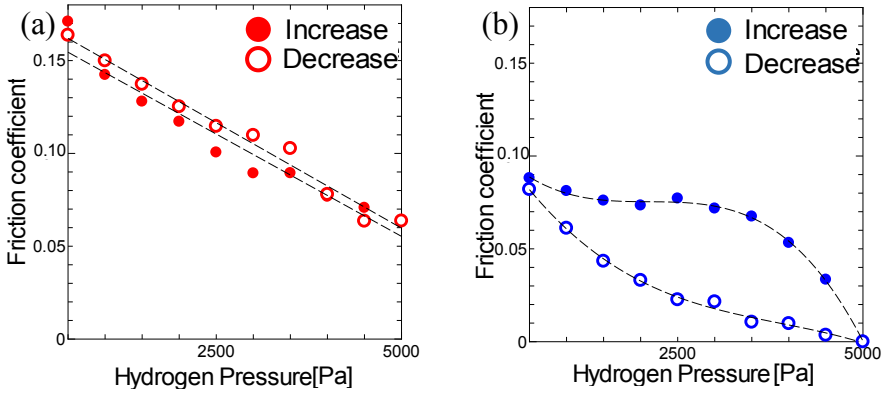

Fig. 1 Effect of hydrogen pressure on average friction coefficients of (a) PVD-DLC and (b) CVD-DLC

Keywords : tribology, diamond-like carbon, hydrogen, vacuum.

Wear

Chair: Martin Priest

Wednesday 11 June 2014 – 11.40-13.00

Room: Suecia

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Rolling-sliding wear of nodular cast iron rollers against wire ropes

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Simplified laboratory wear tests are frequently used for producing comparable data to represent materials in different contact conditions. However, in order to obtain deeper knowledge about the wear behavior of a material in a specific application, component wear tests should be performed. By comparative characterization of wear test samples and actual field-service components, a correlation between the wear test results and the field-service operation findings can be established.

The present work describes wear test results and characterization findings for nodular cast iron in contact with steel wire samples and wire ropes. Grooved nodular cast iron roller components were tested employing a wire-rope bend tester. The contact motion between the roller and the wire rope consists of rolling and sliding perpendicular to the rolling direction, caused by a rotation of the wire rope around its axis. In addition, twin-disc friction and wear tests were carried out with a steel-wire-coated counter-disc. The characterization results for the component and twin-disc test samples were compared to the findings on the wear behavior of a field-service component sample. The wear characterization was carried out by optical microscopy, electron microscopy, and statistical analysis of fatigue wear cracks.

In the component wear test, the higher rope force resulted in higher wear rates and the wear surface showed more severe macroscopic damage. The wear process in the component test samples had advanced in the subsurface region by plastic deformation and internodular crack growth under conditions of contact fatigue. This process resulted in deformation tongues oriented perpendicularly to the rolling direction, and the formation of shallow pits in the wear surface. The twin-disc test produced similar deformation tongues, but in the rolling-sliding direction. In comparison with component wear test samples and the field samples, the twin-disc test sample discs from cast iron revealed material removal in the shape of deeper and larger spalls. This indicates that in the twin-disc tests the fatigue process proceeded by more brittle fracturing than in the case of the field-service and the component test samples. Moreover, in the twin-disc sample, the fatigue cracks extended deeper into the material than in the roller component samples.

The findings indicate that the component wear tests very well simulate the wear behavior of the field-service sample. The contact conditions in the twin-disc test are slightly more severe, but the wear mechanism is quite close to that of the roller samples. The findings will be utilized in the modelling of the rolling-sliding wear mechanisms of nodular cast iron rolls against wire ropes.

Keywords: nodular cast iron, wear mechanism, rolling-sliding, wire rope

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Initiation of wood defibration, tribology at the fiber level

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Mechanical wood pulping is widely used to create fibers to be used in many types of papers. One of the mechanical processes is called stone grinding. In this process a log is ground against a wheel with a surface containing an abrasive, alumina is common. This process consumes lots of energy, amounting to GJ/ton pulp produced. Though commonly used,the exact mechanisms which wear the wood into pulp has not been extensively analyzed,a trial and error approach is most commonly used. In an attempt to design tools that consumes less energy, an understanding of the basic mechanisms is needed.

This work investigates the cell deformation and early fiber separation that initiate the defibration process. An X-ray tomograph (μCT), equipped with a miniature tensile stage, was used to monitor the mechanical behavior of the microstructure in wood when a hard tip was pressed into it step by step.
Subsequent digital image correlation analysis was used to estimate the strain field in the region around the indented tip.The information on regions of high strain—where cracking and fiber separation may initiate—is then compared with images of wood scratched with a diamond tip to simulate a single asperity contact in the industrial tool. From the high strain region numerical stress and strain analyses are made using high-resolution discrete finite element models. This is done to be capable of capture large deformations and rotations and to describe the mechanical behavior on the heterogeneous microscale up to the macroscale. The single tip scratched wood surfaces are also compared with surfaces formed by the industrial grinding process.

Keywords: μCT, defibration, wood-fiber deformation, wood scratching, FEM modeling, wood strain

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Sliding Wear of Quartz and Granite Surfaces

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One key element in reducing wear is to include in the analysis the entire wear environment, i.e., more comprehensive solutions are required. Abrasives are usually considered as the third body in wear related phenomena. Nevertheless, understanding the variables and the effects that the abrasives have on wear can affect the outcome of the materials selection processes quite dramatically. Previously we have conducted studies related to natural abrasives and wear [1-3]. We found that the effect of abrasives changes significantly when the subject of wear is varied. For example, in WC-Co materials quartz causes more wear than granite, but for steels granite is more abrasive than quartz. Moreover, it was concluded that embedded quartz in the sample surface increases friction and affects the further wear rate of certain materials.

The aim of this study was to characterize the properties of two natural abrasives, quartzite and granite, using the ball-on-disc test set-up. For testing, quartzite and granite particles were mounted in a resin and the surfaces of the resulting test pieces were ground. In the ball-on-disc tests, these abrasive surfaces were regarded as the discs, and the balls were made from different steels, zirconia and WC-Co hard metal. These tests were performed using both constant and continuously increasing forces. By increasing the contact force during sliding it was possible to identify different regions from crack generation to delamination. The contact points of the balls were also characterized to see the differences in the minerals attachment to the surfaces. Surface characterizations were done with optical and scanning electron microscopes. In addition, an optical profilometer was used to determine the surface topographies.

The results showed that the highest friction values for both rock surfaces were obtained when the hardness values of the rock and the ball were similar. Moreover, the characterization of the wear tracks provided information about the mineral behavior under a point-like slider and about the material transfer from the ball to the mineral surface.

Keywords: granite, quartzite, ball-on-disc, sliding wear

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The effect of stick-slips on the dislocation structure of LiF single crystals

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The effect of sliding velocity and the direction of sliding have been studied using single crystals of Lithium Fluoride (LiF). The sliding velocity was changed in the range of 1 μ/s – 1 mm/s. Stick-slip tests were performed using ball-on-flat arrangement. Dry friction tests were conducted using a linear ball-on-flat device at room temperature in air (relative humidity 55 ± 5%). The diamond indenter with the radius, R=0.2mm, was slid against a plate of LiF. In order to provide stick-slips the spring with low stiffness was chosen, k = 15 N/m. In order to compare stick-slip motion with sliding, stiff spring was also used, k = 2400 N/m. The friction force and the displacement of indenter relative to LiF plate were measured. The amplitude (A), the difference between the maximum and minimum values of the friction force and the kinetic (average value) of the friction force were chosen for description of stick-slip phenomenon. Dislocation structure around the wear track was revealed by etching of samples before and after friction. The zones of sleep, creep and stick have been revealed for the tracks obtained at different friction conditions. Sticks and creeps are accompanied with expansion or bending of the track. The surfaces after friction were analyzed using optical microscope, scanning electron microscope (SEM) and atomic force microscope (AFM). It has been found that the dislocation structure around the track is associated with stick-creep-slip phenomena. The dislocation structure depends on the sliding velocity and the stiffness of spring. Good correlation between real contact conditions and stick-creep-slip behavior was observed.

Keywords: friction**,** stick-slip, dislocations, structure, single crystal

Test Methods 1

Chair: Bjarke Holl Christensen

Wednesday 11 June 2014 – 11.40-13.00

Room: Dania

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The use of high temperature nanomechanics in designing coatings with improved wear resistance in high-speed machining

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German Fox-Rabinovich, McMaster University, Canada

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Frictional heating results in very high operating temperatures in ultra-high speed machining (e.g. 1000 ºC or more). To extend tool life and operate at higher cutting speed coatings must provide mechanical and thermal protection. Nanoindentation tests used to evaluate the mechanical properties of novel multifunctional PVD coating systems designed for extreme environments such as high speed cutting of hard-to-cut hardened steels or Ni-based aerospace alloys are invariably performed at room temperature. If nanomechanical measurements are to be used reliably in the optimisation of coatings then it is much better that the measurements are performed at the relevant temperature.

This is achieved using a patented method to separately actively heat and control the temperatures of indenter and sample resulting in minimal/no thermal drift during the high temperature indentation. The instrumentation allows reliable nanomechanical testing (e.g. nanoindentation, nano-scratch, micro-pillar compression, micro-cantilever bending) to 750°C and above. To achieve higher temperatures without indenter or sample oxidation an ultra-low drift high temperature vacuum nanoindentation system capable of testing to 1000 °C has been developed.

In this presentation high temperature nanoindentation data for a wide range of multifunctional nitride-based hard coatings on cemented carbide are used to develop robust design rules enabling coating optimisation for different machining applications. Subtle compositional tuning of the coatings resulted in large differences in how their hardness, modulus and H/E vary with increasing temperature [1]. The interrelationship between the high temperature mechanical properties and the coating system's adaptive behaviour and tribo-film formation and ultimate performance is investigated. Overall, the high temperature nanoindentation data show excellent correlation to coating life under severe high speed machining applications.

[1] *Why can TiAlCrSiYN-based adaptive coatings deliver exceptional performance under extreme frictional conditions?* BD Beake et al, Faraday Discussions (2012) 156, 267-278.

Keywords: nanomechanics, high-speed machining, multifunctional coatings, adaptive behaviour

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Introduction of a novel AC²T tribometer especially designed for harsh environment scratch-, adhesion- and hardness investigation up to 1000°C

***M. Varga*[1)]*, *M. Flasch*[1)], *S. Paar*[1)], *E. Badisch*[1)]**

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Wear of materials at high temperatures is a very challenging issue, implying many different mechanisms occurring in the tribocontact. Increasing temperature often leads to microstructural change of materials as well as loss of hardness. At high temperatures oxidation is one of the major damaging processes, additionally corrosion has to be taken into account if aggressive media are present. An abrasive environment further complicates the acting mechanisms. While wear can be increased due to hardness loss also beneficial effects like the formation of mechanically mixed layers, which can increase wear resistance are known.

In order to gain fundamental knowledge of these phenomena a high temperature test device was designed operating up to 1000°C (Fig. 1). The test takes place in vacuum to avoid oxidation and the normal load range is 1 - 500 N. So it is possible to gain hardness progress in a wide temperature and load range and monitor possible microstructural modifications. For characterisation of single abrasive phenomena on a very fundamental level scratch tests at variable loads are proposed. Furthermore, the implementation of application's abrasives will be an important issue in the future.

The interaction of sliding surfaces can be simulated by adhesion testing. Thereto an application specific counterbody can be moved over the sample surface at variable loads. In order to simulate forming conditions the counterbody can be cooled and the temperature difference between workpiece and tool can be simulated in this lab-scale test.

In future, pre-worn samples e.g. after abrasive or erosive loading entailing mechanically mixed layers, will be analysed in order to gain information on the potential of wear reducing mechanisms. Additionally, the influence of corrosion products, for example gained by defined high temperature corrosion tests, on tribological behaviour will be a focus of scientific research.

Finally, it can be claimed that this newly designed HT-HET offers an enormous potential for deeper understanding of fundamental wear phenomena occurring at high temperature.

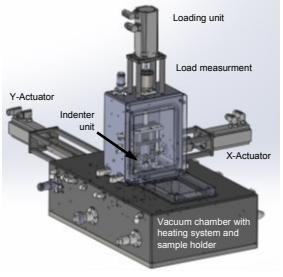

Fig. 1: Schematic view on High Temperature – Harsh Environment Tribometer (HT-HET)

Keywords: high temperature, hardness, abrasion, adhesion, tribology

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Extreme nanomechanics: overcoming the challenges in vacuum nanoindentation to 1000 ºC

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Elevated temperature mechanical and tribological properties are much more relevant for practical wear situations than corresponding measurements at room temperature. However, high temperature nanomechanics and tribology is highly challenging experimentally. To overcome these challenges we have developed instrumentation (the NanoTest) with (1) active heating of the sample and the indenter (2) horizontal loading to avoid convection at the displacement sensor (3) patented stage design (4) patented thermal control method. By separately actively heating and controlling the temperatures of indenter and sample there is minimal/no thermal drift during the high temperature indentation and measurements can be performed as reliably as at room temperature.

A range nanomechanical and tribological tests such as nanoindentation [1-2], nano-scratch, nano-wear, micro-pillar compression [2], nano-friction [3], creep, micro-cantilever bending can be performed to 750 °C or more. Above 500 °C it is necessary to use Argon purging to limit oxidation of samples and the diamond indenter although the efficiency of this decreases over 750 °C.

To achieve higher temperatures without indenter or sample oxidation an ultra-low drift high temperature vacuum nanomechanics/tribology system capable of testing to 1000 °C has been recently developed [4]. This presentation describes the development of the high temperature vacuum system and its use at high temperature on a wide range of metals, alloys, ceramics and coatings.

[1] *Mechanical properties of solid oxide fuel cell glass-ceramic seal at high Temperatures*, J. Milhans, D.S. Li, M. Khaleel, X. Sun, Marwan S. Al-Haik, A. Harris, H. Garmestani, Journal of Power Sources 196, (2011) 5599–5603

[2] *High temperature microcompression and nanoindentation in vacuum*, S.K. Korte, R.J. Stearn, J.M. Wheeler and W.J. Clegg, J. Mater. Res. 27, (2012) 167-176.

[3] *Nanoscale Friction Measurements Up to 750 ºC*, J.F. Smith, V.M. Vishnyakov, M.I. Davies and B.D. Beake, Tribol Lett (2013) DOI 10.1007/s11249-013-0102-5.

[4] *The NanoTest Xtreme*. www.micromaterials.co.uk

Keywords: nanomechanics, high temperature tribology, vacuum nanoindentation

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Effect of temperature control in high temperature tribology

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Friction and wear is measured in an environment where both the articulating parts are subjected to high temperature. Although, in some applications like metal forming (extrusion, die casting) only one articulating surface is at 900 deg C or higher. It is important for the bench top testers to atleast mimic the temperature difference occurring during the metal forming process. Here, we have developed a friction and wear testing method using Ducom high temperature ball on disc tester that can control the ball and disc temperature independent of each other within 5 deg C error. Alumina ball was loaded on an uni-directionally sliding inconel 625 disc, ball and disc heating was controlled independently upto 900 deg C using induction coil heating. Coefficient of friction was acquired during variable heating patterns i.e. heating only inconel disc and both inconel disc and alumina ball at the rate of 11 deg C/ min upto 900 deg C.. Coefficient of friction was the lowest when only inconel disc was subjected to heating i.e. 0.2 and it was 2 times lower then coefficient of friction when both alumina and inconel was heated. Post wear analysis using white light interferometry indicates 6 times lower wear on inconel disc when only inconel disc is heated compared to both alumina and inconel is heated. This suggests that controlled variable heating patterns of the ball and disc is important for high temperature tribology.

Keywords: metal forming, high temperature, inconel, heating pattern, coefficient of friction, wear

Bio Tribology

Chair: Lars Pleth Nielsen

Wednesday 11 June 2014 – 12.00-12.40

Room: Nortvegia

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The influence of diamond like carbon coated surfaces on friction and film thickness to a bovine ceramic lubrication condition

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Issues: Diamond like carbon (DLC) is a promising material in many engineering interfaces due to its excellent tribological performance. Very recently, it has been extensively tested as biotribological surfaces, and reported to have very lower friction and wear. However, very little studies have been carried out identifying its lubrication mechanism (film thickness) under a bovine serum lubrication mechanism. Therefore, the aim of the study is to understand the lubrication mechanism of DLC to a simulated hip joints condition.

Method: A spherical head was manufactured to a diameter of 25 mm from a stainless steel bar, and polished to a mirror type surface finishing. Then, these have been coated with DLC by using a physical vapour depositing. Hardness, elasticity, wettability and surface roughness profiles were measured prior to the tribology test. In the tribology test, the DLC coated ball rubbed against Cr coated glass disk, where 25% bovine serum was used a lubricant and temperature was maintained at 37^0 C. Film thickness and a frictional force was measured by a An optical interferometry and a torque sensor respectively. Experiment was repeated with reciprocating motions, and different contact pressures. The outcomes were compared with lubrication film thickness and friction coefficient measured at similar conditions to a bearing steel ball.

Results and conclusion: Loads and speeds were found to be influencing factors to film thickness and friction coefficient of both materials. Moreover, DLC produced lower and consistence friction coefficient profiles compared to steel at all of the experiment conditions. Film thickness was fluctuated to both materials, however most cases, thicker to DLC surface. Since the contact pressure was relatively high, the disk material was severely damaged by DLC within few minutes of experiment, whereas both ball and disk surfaces were severely damaged in case of steel ball. Moreover, DLC surfaces were found to be de-laminated few spot. Therefore, DLC has better tribological performance in both boundary and mixed lubricant regime compare to steel. However adhesion of DLC need to be improved and its courterface material should be carefully chosen.

Keywords: Diamond like carbon, bovine serum, friction coefficient, film thickness

Studying Water Based Lubricant Behavior in Mini-Channel

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[2] Biomaterials, Biomechanics and Tissue Engineering Group, Dept. of Materials Science and Metallurgy, Technical University of Catalonia, Barcelona, Spain
[3]Division of Fluid and Experimental Mechanics, Luleå University of Technology, 97187, Luleå, Sweden.
[4] Water Power Laboratory, Norwegian University of Science and Technology, Norway.

Oral presentation

* Presenting author: Alaleh Safari (alaleh.safari@ltu.se).

Keywords: TJR, joint lubricant, wear particles, micro-PIV

Abstract

One of the most common causes of failures in total joint replacements is the generation of wear particles within the joint that leads to the micro separation at the implant-bone interface. This contributes to bone lost aseptic loosening of the implant, requiring eventually its replacement.
Many studies have been carried out to improve the wear characteristics of bearing surfaces in total joint replacement (TJR). From lubrication point of view the friction behavior of surfaces and rheology of the joint lubricant (Synovial fluid) were extensively studied. However, not much attention was paid to the interaction between the lubricant and the bearing surfaces. The aim of this study is to develop a methodology for studying the behavior of water based lubricant in a micro-channel. For this purpose, Micro-PIV (Particle Image velocimetry) was used in order to characterize the lubricant behavior. Experimental models made of relevant materials such as ultra high molecular weight polyethylene, Cobalt-Chromium-Molybdenum alloy and Titanium-Aluminum-Vanadium alloy with 1 and 1.5 mm width, 45 mm length and 2 mm depth experimentally investigated.

Wear & Fretting

Chair: Sergei Glavatskih

Wednesday 11 June 2014 – 14.00-15.20

Room: Suecia

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Computational multiscale modelling concept and supporting experimental testing procedures for material wear behaviour under severe environments

Anssi Laukkanen[1], Päivi Kivikytö-Reponen[1,*], Antti Vaajoki[1], Richard Waudby[1], Tom Andersson[1], Marjaana Karhu[1], Marian Apostol[2], Kati Valtonen[2], Veli-Tapani Kuokkala[2]

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Abstract: Sustainable design is a growing trend driven by resource scarcity, safety and environmental aspects, and volatile prices of energy and raw materials. Traditionally materials for severe industrial conditions, such as wear, corrosion, or elevated temperatures, have been designed based on the material performance and cost issues, largely by trial and error. For process optimization and material life cycle estimating purposes computational modelling aided material design is applied to improve and accelerate the design procedures. Moreover, it is challenging to mimic in laboratory conditions realistic operational environment during abrasive, erosive, and impact type wear, and modelling can be applied as a tool for transferability material properties and performance measures.

This paper presents a computational multiscale modelling concept and supporting experimental testing procedures for elastomer materials designed for severe environments, such as applications involving repeated impacts of hard abrasive particles on surfaces at high or moderate strain rates. The approach was to model behaviour and carry out lifetime predictions by studying different types of single and erosive impacts between hard particles and an elastomer surface. The model was verified by experimental testing procedures using high velocity particle impactor, surface scratch testing and centrifugal accelerator with various impact angles.

Keywords: modelling, material testing, impact, wear, severe environments

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Effect of the contact angle on the impact-sliding wear of nitrided stainless steel at 400˚C

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In the sliding parts of the industrial machines, unexpected vibrations generated from external parts could lead severe abnormal wear. In most of case, it might be caused by impact-sliding wear. In order to find the solution for it, it is important to understand the mechanism of impact-sliding wear. So far, authors have reported the effect of impact energy and number of cycles on wear by using impact-sliding wear test rig. In this study, focusing on the effect of the contact angles on wear, we conducted the impact-sliding wear test at 400˚C in air.
The impact-sliding wear tests were conducted by using cross-cylinder type. Cylindrical specimens (10mm of diameter and 10mm of length) were used for the test. Specimens were made of stainless steel 310S. Two kinds of nitriding treatments were treated on the specimens: gas nitriding and ion nitriding. Both nitriding were used in combination as a pair. Test conditions were shown in Table1.

One of the test results is shown in figure 1. Wear volumes shows sum of the pair of specimens. It showed the tendency of decrease with the contact angles increase. It is due to the difference of contact condition between both specimens and elimination of the wear debris on the sliding surfaces.

Table 1 Test conditions

Temperature ˚C	400
Impact energy mJ	4
Number of cycles	5×10^5
Frequency Hz	16
Contact angle ˚	45, 60, 90

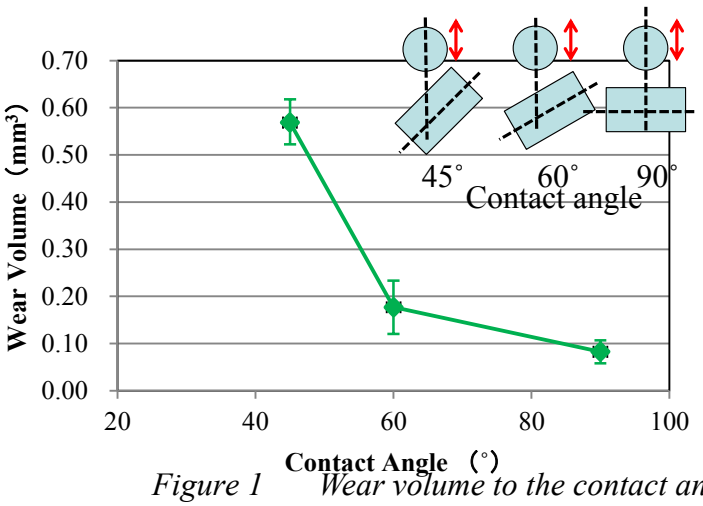

Figure 1 Wear volume to the contact angles

Keywords: impact-sliding wear, contact angle, nitriding, stainless steel

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Applying the digital image correlation method to fretting contact

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Fretting occurs between contacting parts that undergo small relative oscillatory movement. It can cause serious damage to machine components, either by decreasing fatigue life (fretting fatigue) or by wearing the contacting parts (fretting wear). The relative movement, i.e. slip, between contacting parts and the friction coefficient are both important fretting parameters. Numerical fretting contact models are used to calculate quantities, such as slip, contact tractions and further stresses in contacting bodies for fatigue life calculations. In the models, using the proper friction coefficient as an input value is of utmost importance. However, experimental measurement of the friction coefficient from fretting contacts is not straightforward: neither is the measurement of the micrometer-level motion between the contacting parts.

In this study, the digital image correlation (DIC) method is applied to a fretting contact. A DIC system, consisting of a digital camera extended with a long-distance microscope, is implemented into an in-house complete contact fretting test device. Complete contact means that the contact size is independent of the applied normal load, i.e., the contact has ‘sharp’ edges. Theoretically, this leads to singular contact traction field. The material used here is quenched and tempered steel. DIC is employed to measure the local displacement field at the contact edge. The size of the slip regime and the micrometer-level slip amplitude can be directly determined. The experimental system allows displacement field measurement at specified time intervals during an entire fretting fatigue test, consisting of several million loading cycles of the test specimen. This makes it possible to establish the development of the slip amplitude and the slip regime size throughout a fretting test.

Keywords: fretting, complete contact, slip, digital image correlation, DIC.

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Fretting wear behaviour of MoS_2 dry film lubricant

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**presenting author*

Dry film lubricants (DFL) are used as palliative coatings to prevent fretting wear. In this work fretting tests are carried out on coated Ti6Al4V cylinders on coated flat samples under dry sliding conditions, using an amplitude of 300mm, 2.5Hz frequency and 575N normal load. During the tests the coefficient of friction (CoF) was monitored with time, with tests being terminated when the coefficient of friction reached 0.7. Wear scars were analysed by profilometry and SEM to elucidate wear mechanisms. Results show that CoF initially increases rapidly to 0.4, this is then followed by a plateau region that finishes in a sudden step decrease in CoF following which CoF rises steadily. This behaviour is shown to be characteristic and interrupted tests are presented to allow elucidation of the wear scar at different stages in the lifetime and thus aid an understanding of the mechanisms of degradation which control the tribological behaviour.

Keywords: fretting, friction, tribology, solid lubricant coating, dry sliding wear

Test Methods 2

Chair: Dirk Drees

Wednesday 11 June 2014 – 14.00-15.20

Room: Dania

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Film thickness measurements in a running hydrostatic swash plate type unit using ultrasound

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The present work describes the measurement of the oil film thickness in the range of a few micrometers in an operating hydrostatic unit using ultrasound. The investigated tribological system consists of a rotating steel cylinder block and a stationary bi-metal valve plate under static and hydrodynamic lubrication. The film thickness has been recorded in a wide range of operating conditions, pressure between 100 to 300 bar and rotational speed between 500 and 3000 rpm, to support a deeper understanding of the system. Temperature sensors were implemented next to the ultrasound sensors to compensate the ultrasound signal amplitude and phase change due to temperature dependent impedances. To confirm the results, especially the presence of purposely intended zero-film conditions, wear profiles of the running surface were taken.

In contrast to past measuring methods, the ultrasound technique shows a significant improvement in resolution allowing the real-time observation of film thickness oscillations with cylinder block and piston frequency. Steady-state measurements confirm the system behavior observed in transient operation and zero-film conditions with respect to hardware configuration were detected. The findings will be utilized to support current development activities and to improve simulation models used for film thickness predictions.

Keywords: ultrasound, hydrostatic swash plate unit, oil film thickness, cylinder block, valve plate

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Validation of a New Tribological Test Bench for Lightweight Hydraulic Components

***M.Sc. Markus Blust* (IPEK), Dipl.-Ing. Benoit Lorentz (IPEK)**

M.Sc. Markus Blust (oral presentation)

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In mobile systems, and especially for automotive applications, reducing moving masses becomes even more relevant. Reducing moving masses decreases the energy consumption and consequently the CO_2 emission of the overall mobile systems.

Present paper focuses on tribological contacts occurring in "lightweight" hydraulic systems, often subject to oversizing, leading to unnecessary high masses of the systems and contributing to high costs. As demonstrator, the main component of a hydraulic power train (here an axial piston variable pump) is taken under investigation. A possible strategy to reduce the overall mass of an axial piston variable pump may consist in replacing steel-components with polymeric material or hybrid design components. This way induces changes of tribological properties of the system as polymeric or hybrid design components in such tribological contacts are still unknown yet.

To improve scientific understanding of these tribological contacts between cited lightweight materials, a test bench was developed at the IPEK – Institute of Product Engineering. The test bench enables analyzing the tribological behavior of a typical contact occurring in the axial piston variable pump: contact between cylinder and control plate. The developed test bench reproduces real tribological conditions observed in the tested system and aim at establishing the tribological behavior of the contact observed in the real system. A description of the modeling as well as a validation of the test bench are presented in the proposed paper. Additionally, first results of the friction behavior will be shown as well as measured wear rates.

Keywords: hydraulic components, tribology of materials, system tribology

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Test rig for drag force measurements

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IK4-Tekniker, C\ Iñaki Goenaga 5, 20600, Eibar, Spain

**Presenting author*

Ships' performance is affected by the drag force at the underwater hull. This drag force depends on the physical and biological hull roughness. If the former can be controlled by the manufacturing process and by means of opportune anti-corrosive surface treatments, the latter needs several developments for avoiding bio fouling. In order to test these developments at laboratory scale a test rig has been designed and assembled.

It consists of a 200 mm diameter stationary cylinder fixed to a frame through a torque meter and sank into a rotating tank of marine water. The measuring device is uncoupled from the actuation part allowing a precise recording of the drag force. The gap between the stationary test cylinder and the tank can be decided changing the tank inner diameter, therefore, both Couette and turbulent flow can be reproduced.

Precise measurements of the drag force in two ranges 0-1 Nm and 0-10 Nm can be carried out. The opportune dimensioning of the system allows reaching velocities up to 30 knots for a rotating speed of 1500 rpm. The performances of the test rig and its limits are herein illustrated.

Keywords: drag force, tribometer, turbulent flow, hull roughness

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Surface plasmon resonance measurements of adsorbed films under fluid lubrication conditions

Satoru Maegawa, Anna Koseki, Fumihiro Itoigawa, Takashi Nakamura

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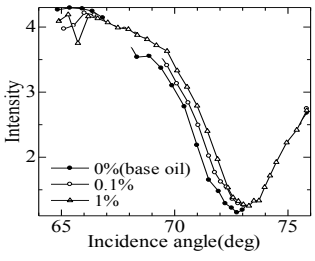
Recently, the in-situ observations of surface chemical structures based on surface plasmon resonance (SPR) phenomenon have been focused on due to their high sensitivity, high time resolution and simple construction. In several situations, using SPR signals from the surfaces, the adsorbed film thickness, surface coverage, or surface concentrations, etc., are estimated.

The aim of this study is to introduce the SPR measurement technique for monitoring the adsorption processes of fatty acids in fluid lubrication systems. The experimental apparatus used in this study employs a fluid-lubricated contact between a flat surface of a semicylinder prism (made of polycarbonate) and a metal roller (made of SAE4135). The clearance between them was set to be 50 μm, i.e, thickness of fluid lubrication film: 50 μm. In order to generate SPR signals, the Ag SPR sensing film (thickness: approximately 50 nm) was deposited onto the prism surface. In the test, base oil (Hexadecane) and a small amount of additive (0.1 and 1 mass% Oleic acid) are dropped into the clearance space.

Figure 1 shows the change in SPR signal curves under static conditions (i.e., without rolling). It means that the method can measure the small change of the permittivity resulting from the increased concentration of Oleic acids; the dependence of adsorption properties on the concentration of additive can be qualitatively observed by measuring SPR signals. Figure 2 shows time changes SPR signals under dynamic condition (i.e., with rolling). This result shows some of adsorption characteristics of fatty acids in fluid lubrication conditions. The adsorbed film of oleic acid is developed on a time scale of 10 minutes, and the growth rate depends on the concentration of oleic acid. In addition, it is suggested that mechanical shearing is an important factor to promote the ability of forming adsorbed layers. Through the experimental test, it was found that the SPR measurement technique have a high potential for monitoring adsorption processes of fatty acid films under lubrication conditions.

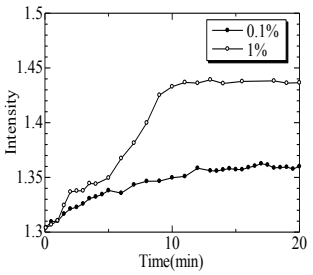


Base oil: Hexadecane

Additive: Oleic acid

Oil thickness: 50 μm

Fig. 1 SPR curves under the static test.



Base oil: Hexadecane

Additive: Oleic acid

Fig. 2 Time changes of $I_{reflect}$ under the dynamic test.

Keywords: surface plasmon resonance, in-situ observation, adsorbed film, and fluid lubrication.

Modelling 3

Chair: Kristian Tønder

Wednesday 11 June 2014 – 14.00-15.20

Room: Nortvegia

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Cavitation analysis of a journal bearing - Finite Element modelling and experimental studies

***C.K. Christiansen*[1]*, *P. Klit*[1], *J.H. Walther*[1], *A. Vølund*[2]**

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This paper will present a two-sided approach to establish understanding of the cavitation phenomenon in a dynamically loaded journal bearing, more specifically the engine bearings of a large two-stroke marine diesel engine. Journal bearings are used in a wide range of applications due to their simplicity and derived low cost but also a reasonable load carrying capacity. On the other hand, one of the most often mentioned disadvantages of the journal bearing is the converging-diverging geometry making it prone to cavitation. A typical area of application for journal bearings is combustion engines. Here the journal bearing plays a vital role especially as main and crosshead bearings transmitting the combustion forces. Those forces vary highly during one combustion cycle which is further influencing the load carrying capacity. For machinery operating at low RPM's such as large two-stroke marine diesel engines, as featured in this work, this is critical. Reynolds equation is solved numerically using Finite Elements incorporating a cavitation algorithm and dynamic coefficients. To the author's knowledge this particular combination is novel. Validation of the results is done against the Ruston–Hornsby 6 Veb-X Mk III engine. Besides the numerical investigations a cavitation test rig has been developed. With this rig it has become possible to generate cavitation under controlled conditions in terms of load/eccentricity and rotational speed. The development of cavitation in time in terms of position and distribution can be visually recorded. The obtained numerical results are compared with the experimental results.

Keywords: cavitation, journal bearing, Finite Element, filling ratio, test rig

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Dynamic and tribological analysis of a toroidal CVT

Keith Philpot* and *Romeo Glovnea

Department of Engineering and Design, University of Sussex

Continuously variable transmissions (CVT) are mechanical transmission, which unlike ordinary gearboxes offer seamless change of the transmission ratio through a theoretically infinite range. There are many design configurations of these transmissions however they all have in common the continuous change of a length or angular dimension which results in an adjustment of the velocity of the output element. Most CVT designs include tribological contacts which can transmit power while changing the geometrical configuration of the contacting elements. A distinct kind of CVTs includes devices in which the tangential force between rotating elements is transmitted through a thin lubricant film, known as traction drives, where the lubricant film works in the elastohydrodynamic (EHD) regime of lubrication. Of these, the toroidal design is best known, probably because of the devices of this type used in automotive applications. The working principle and calculations of a toroidal-type CVT capable of automatically adjusting the transmission ratio function of the resistive torque was presented in a number of papers by the authors. A schematic of the device is shown in Figure 1.

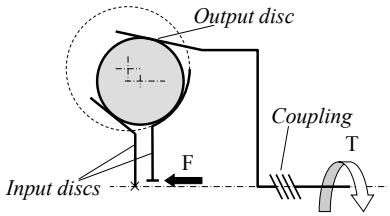

Figure 1

The main elements of the traction drive are the input discs, one conical and the other toroida,l with a conical output disc, between which a convenient number of spherical elements are placed. The power is transmitted from the input to the output discs through the shearing of the EHD film formed in the contacts between these discs and the intermediary spherical elements. The toroidal disc rotates with the input shaft but is free to move axially, thus when a torque is applied to the output shaft, the coupling between this and the output disc displaces axially the later which in turn forces the balls to move in radial direction and consequently change the transmission ratio. In the present study an analysis of the relative kinematics on the contact areas between the discs and balls is carried out. The relative motion between these elements consists of spin and side slip imposed over the longitudinal slip. The later is obviously the motion used to transmit power while the former are parasitic motions. Understanding this kinematics is important for the design and modelling of the CVT because these relative motions cause shear of the EHD film and provide the tangential force which drives the elements. The lubricant is modelled as a non-Newtonian fluid using a multi-grid multi-level method to calculate the traction force on the contacts. These are subsequently used to evaluate the dynamic response of the CVT to a rapid variation of the input/output parameters.

Keywords: CVT, EHD, traction, modelling, dynamics

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Comparison of Four Numerical Methods of EHL Modeling

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** : Presenting author*

Several methods to model Elastohydrodynamic Lubrication in non-conformal contacts have been presented over the years. Two of the more commonly used methods are the Finite Difference method by Houpert and Hamrock[a] and the multigrid method by Lubrecht[b]. These two numerical methods can obtain convergence of the pressure and film thickness curves for high input loads. A finite element model for low loads has been developed as part of the current work and its advantages and limitations compared to the models by Houpert & Hamrock and Lubrecht are studied. The Finite Difference model by Houpert and Hamrock is extended to study slip in EHL contacts at low loads. The advantages and limitations of this model is compared to the previously mentioned three models.

The Finite Difference approach by Houpert and Hamrock to model EHL in isothermal, non-conformal contacts by applying the Newton Raphson method to solve the highly coupled, non-linear Reynolds equation and the elasticity equation is a popular method to obtain the pressure and film-thickness curves at high loads. Input loads corresponding to a maximum Hertzian pressure of 2 GPa have been applied using this method. This method of solution has been extended by Houpert and Hamrock to solve the EHL equations for slip at low loads and slide-roll ratios. At high loads or slide-roll ratios, the high temperature at the contacts limits this isothermal model in its use.

A finite element model using 4 node quadrilateral elements was used to solve Reynolds equations at low loads. The finite element model does not converge for high loads. The advantages and limitations of this model are discussed.

Lubrecht used a multigrid method to resolve convergence problems in the EHL model at high loads. The coarse mesh in the multigrid method eliminates the low frequency errors, while the fine mesh eliminates the high frequency errors. This interpolation of data between grids of varying number of elements and elimination of errors at each level leads to faster convergence of the pressure and film thickness curves at high loads. Input loads corresponding to a maximum Hertzian pressure of 4 GPa have been solved using this method. The multigrid method has been further extended to study the EHL behavior in contacts where one of the surfaces in contact is textured. The advantages and limitations of this method in relation to the other methods are discussed.

[a] – Houpert L.G and Hamrock B.J. ., "Fast Approach for Calculating Film Thicknesses and Pressures in Elastohydrodynamically Lubricated Contacts at High Loads,"(1986)

[b] – Lubrecht A.A., "Numerical Solution of the EHL Line and Point Contact Problem Using Multigrid Techniques," PhD Thesis, (1987)

Keywords : elastohydrodynamic lubrication, multigrid method, finite element method, finite difference method

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A Non-Newtonian THD Lubrication Model for Journal Bearings

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Presenting author: Shiuh-Hwa Shyu

A general lubrication model was developed for laminar and turbulent thermohydrodynamic (THD) journal bearings with non-Newtonian effects. The Navier-Stokes and energy equations were solved with the molecular viscosity modeled with the power law and as a function of temperature. A Legendre collocation method was used in the cross-film direction while the axial direction was discretized with a staggered system. The model was validated by comparing with the Reynolds equation and a study in the literature. A parametric study was conducted to find that the load capacity, friction coefficient and the THD effects on the load capacity increase with the power-law index.

Keywords: non-Newtonian fluid, turbulent flow, thermohydrodynamic, journal bearing, Legendre collocation, Navier-Stokes equations

PLENARY SESSION 3

Thursday 12 June 2014 - 08.40-09.20

Professor Mathew Mate

Chair: Ion Sivebæk

Improved Understanding of Lubrication at the Molecular level and its Impact on Technology

Dr. C. Mathew Mate

HGST, a Western Digital company, San Jose, California, USA

Abstract:

The past thirty years has seen a tremendous increase in the number of experimental results elucidating how lubricants work at the molecular scale to reduce friction and wear. Over the same period of time, major advances have also occurred in computer modeling of lubricant behavior over a wide range of length scales: from atomic-scale molecular dynamic (MD) simulations to macroscale computational fluid dynamics (CDF) modeling.

In this talk, I will review the progress that has been in improving our molecular level understanding of lubrication from these modern experimental techniques, simulations, and theory. I will also discuss how these advancements in molecular level understanding have led to major technological advances, with a particular emphasis on the tribological advances achieved by the disk drive industry that I work in. Finally, I will discuss opportunities for achieving advancements in other technologies and for even enabling entirely new technologies through better molecular level understanding of friction, lubrication, and adhesion.

Keywords: lubrication, disk drive tribology

Biography:

Bachelor in Engineering Science from the University of California at Berkeley in 1981 and PhD in Physics from the same university in 1986. Afterwards he began to work at the IBM Almaden Research Center in the area of tribology research. When IBM sold its disk drive business to Hitachi in 2003, his research organization became part of Hitachi Global Storage Technologies; and, then when Hitachi sold this business to Western Digital in 2012, it became part of HGST, a Western Digital company. Dr. Mate's research interests at IBM, Hitachi, and HGST have focused on understanding how friction and lubrication occur at the atomic and molecular levels. Initially, this work has involved pioneering the use of the atomic force microscope to study tribological phenomena. He has also conducted seminal studies on the physical properties of molecularly thin polymer films that are important for lubrication. More recently, this research has centred on understanding friction, lubrication, and wear of recording heads flying over disk surfaces inside of disk drives. In 2001, he was awarded the MRS Medal from the Materials Research Society in recognition of his pioneering studies of friction at the atomic and molecular level; and, in 2012, he received the International Award from the Society of Tribology and Lubrication Engineers.

Coatings 1

Chair: Helena Ronkainen

Thursday 12 June 2014 – 09.40-11.20

Room: Suecia

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Tribological and mechanical properties of Cr_{2N}-11Ag – coatings deposited on Cr-V ledeburitic steel

***Pavel Bílek*[1], Peter Jurči[1], Michal Novák[1,2], Mária Hudáková[1], Ľubomír Čaplovič[1],**

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[2] *Institute of Materials Research, Slovak Academy of Sciences, Watsonova 47, 04001, Košice, Slovak Republic*

4.7 μm thick Cr_2N-Ag nanocomposite coatings, containing 11 wt.% Ag solid lubricant, were deposited on substrate made of Cr-V ledeburitic tool steel Vanadis 6 by reactive magnetron sputtering, at a deposition temperature of 500 ºC, using pure Cr and Ag targets, in a composite low pressure N_2/Ar atmosphere. The nanohardness of the Cr_2N-11Ag film was 17.86 ± 0.79 GPa, e.g. it was slightly higher than that of the pure Cr_2N, Cr_2N-3 wt.% Ag and Cr_2N-7 wt.%Ag coatings, respectively. The Young modulus was 280 ± 7 GPa, e.g. it was not influenced negatively by elevated silver content, also. The Cr_2N-11Ag film exhibited good adhesion on the substrate – the first critical loads, related to the first indications of side flaking of the films, established by scratch-testing method, ranged between 34 and 40 N. Tribological testing using a pin-on-disc apparatus has been realized at ambient and elevated temperatures: 300, 400 and 500 °C, respectively. The balls made of Al_2O_3 and 100Cr6, respectively, have been used as counterparts. Wear tracks after pin-on-disc testing were analyzed by scanning electron microscopy and microanalysis. The self-lubricant effect is dependent on transport of lubricious Ag within the Cr_2N matrix to the surface of coatings. The experiments have shown the strong dependence of tribological properties on the temperature. At ambient temperature, the friction coefficient μ against alumina was 0.70 and it was reduced to 0.34 when tested at temperatures of 400 °C and 500 °C, respectively. The reduction of μ makes of about 52 %. Compared to the films with lower silver content, the reduction of the friction coefficient was found to be similar with increasing temperature. The friction coefficient of Cr_2N-11Ag film against 100Cr6 was 0.57, e.g it was practically the same than that of Cr_2N-7Ag. Obtained results infer that there is good opportunity to design the Cr_2N-Ag film for specific tribological applications, through proper choice of both the deposition temperature and the silver addition into the basic Cr_2N coating.

Keywords: Vanadis 6, PVD, chromium nitride with silver, pin-on-disk, nanohardness, scratch-test.

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Friction investigation with thermally sprayed Fe-based coatings for application on cylinder running surfaces in combustion engines

Beate Schleif, Dipl.-Ing.[1], Wolfram Wagener, Dr.-Ing.[2], Ludger Deters, Prof. Dr.-Ing.[3]

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Modern combustion engines for automobile applications are demanded to show improved performance resulting in higher loads and requirements, e.g. for the cylinder running surface. To ensure an unproblematic operation over the whole life time of the component, the running surface needs to be resistant against scuffing and wear. Therefore, the current BMW four-cylinder gasoline engine has a ferrous coating applied on the aluminium crank case by wire-arc spray. This coating reduces the weight and thermal deformations of the cylinder bores in operation compared to gray cast iron liners while having higher wear resistance and scuffing load capacity than hypereutectic aluminium liners. In addition, the reduction of frictional losses is aimed for in order to reduce CO_2-emissions. The tribological system cylinder liner / piston is one of the main focuses for optimization because it contributes the largest part to the total engine losses. On the one hand, the chemical and structural composition of thermal spray coatings is dependent on the coating process. Due to the lamellar structure containing pores and oxidized phases, such coatings do not behave like the cast alloys when exposed to friction. On the other hand, heterogeneous materials can be applied in a way that the phases serve different tasks in the function of the coating, e.g. resulting in lower friction. Therefore, selected metallic materials are applied on cylinder bores by wire-arc spray and their behaviour in boundary friction is evaluated in an oscillating tribometer. Subsequent analyses determine the character of the coatings and the built tribo-layers.

Keywords: thermal spray coating, wire-arc spray, cylinder bore, boundary friction

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Friction and wear resistance of plasmapolymeric coatings applied on elastomers

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Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung

Using plasmapolymeric coatings on flat elastomer plates as well as on dynamic sealing components a significant reduction of friction and wear was determined in the past[1,2,3]. Quantifying the improvement of wear resistance enhanced lifetime tests were performed as a function of the applied film thickness.

The flat elastomer plates were coated with a plasmapolymeric film ($SiO_xC_yH_z$) in a plasma enhanced chemical vapour deposition (PECVD) process. The film thickness was varied from 0.66 to 3.9 µm. The investigated substrate type was acrylic rubber (ACM).

The friction of elastomers was investigated using an Universal Material Tester (UMT3) system with oscillating Pin-on-plate contact geometry. The counterpart in the tribological tests was a 100Cr6 steel ball with a diameter of 10 mm. The tribological tests were runned dry in ambient conditions with a velocity of 200 mm/s, a stroke length of 11 mm, and normal force of 4.7 N. The used normal force represents an initial Hertzian pressure of 1.5 MPa. The oscillating measurement setup was chosen to save test time subjecting premature wear. In spite of that fact the tests were performed 24, 60, and more hours.

It was found that the set in of the wear depended on the film thickness. The set in of wear was detected at the steep rise of the coefficient of friction. The wear resistance decreased with increasing film thickness. A minimum film thickness is required.

The beneficial wear resistance of the thinnest 0.66 µm film depicts the improved lifetime in combination with reduced friction at low costs due to short film deposition time. In contrast to the uncoated sample the coated ones exhibited only a polished like wear track. The counterparts revealed heavy wear at increased coating thickness on the elastomers. The results at the investigated dry contact demonstrate emergency running properties. The coefficient of friction was in the range of 0.15 to 0.17. It revealed that the coefficient of friction was independent on the film thickness.

Keywords: plasmapolymeric coating, elastomer, rubber, friction reduction, wear resistance, energy saving, CO2 saving

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Nanotribological Properties of Pb Thin Films

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Presenter: Esteban Broitman

It is well known that soft metals, such as Pb, when deposited as films on a relatively hard substrate can have low friction and wear in macrotribological situations. Typically, the solid lubrication process of soft metal thin films occurs by shear within the film, with a friction force strongly dependent on the thickness of the coatings: the minimum value occurs for a critical film thickness related to its roughness. Surprisingly, there is no available experimental data regarding the friction and wear of soft metals at the nanoscale.

In this work, we compare the nanomechanical and nanotribological properties of 250 nm thick Pb films deposited on Si substrates at room temperature by thermal evaporation (TE) and pulsed laser deposition (PLD) techniques. Films were investigated by scanning electron microscopy, surface probe microscopy (SPM), and X-ray diffraction in θ-2θ geometry to determine their morphology, RMS roughness, and microstructure, respectively. Results show that as-deposited PLD and TE films present a similar polycrystalline structure, with RMS roughness of 14 nm and 10 nm, respectively. A grainy surface structure with well-defined individual grains and some voids between them is observed. The morphology of TE Pb films is much more irregular than that observed in PLD films.

Nano-mechanical and nano-tribological properties were studied with a Triboindenter TI-950 from Hysitron. Hardness and elastic modulus, measured with a diamond Berkovich probe, vary from 1.1 to 0.8 GPa and from 70 to 43 GPa for PLD and TE films, respectively. A reciprocal friction test, using a conical diamond probe of 5 μm diameter with loads varying from 5 to 500 μN, show that PLD films have lower friction coefficient and wear rate.

Our study reveals that, at the nanoscale, Pb films do not show the same advantageous lubricious properties measured at macroscale. The analysis of the surfaces by SPM shows that the material removal mechanism is mainly plowing. The wear process through the plowing of the tip depends on the film hardness: at the each applied load, the wear is lower for the harder PLD film. During the first cycles of the reciprocal tests, the friction coefficient is strongly influenced by surface roughness, but as soon as the wear starts to reduce the roughness, the contribution of plowing component to the total friction coefficient becomes more predominant.

Keywords: nanotribology; Pb films; soft metals; friction; wear; nanoindentation

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Evaluation of Durability of SOG-layers on Steel Surfaces by Wear and Scratch Tests

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Steel moulds with high precision surfaces are being used in various branches. Process aspects, like tool life and tribological properties, as well as design issues are of great importance. This work summarises experimental studies performed to test durability properties of SOG (spin-on-glass)-layers on steel surfaces. This coating technique is based on a newly developed method for surface preparation of tools which has been demonstrated to be durable for more than 66.000 replications in injection moulding processes without loss of surface fidelity. The procedure allows surface roughness reduction from approximately 200 nm Ra down to some few nm for high gloss applications, as well as easy transfer of large-area functional nanostructures on complex 3D surfaces.

Three different types of surfaces were investigated: SOG-layered metal surfaces with three different layer thicknesses, one ingot casted and one electro slag remelted material (with hardness level of 950 and 2500 MPa, respectively). The metal surfaces were ground and polished to mirror-like finishes.

Three circular samples of each type were rubbed against a hard steel ball of 6.35 mm radius on a commercial pin-on-disk tribometer. To resemble the molding process a sliding speed of 2 mm/s and a load of 8 N were chosen. The tests were performed with 5 minutes intervals until the first damage on the surface were observed. In parallel, scratch tests were performed in the same tribometer. The surfaces were measured in-situ by a portable microscope and a stylus, and afterwards by a white light interferometer and scanning electron microscope to evaluate the size of the wear/scratch traces.

The surface type with the longest time to damage and/or smallest wear/scratch traces was considered to be the most durable one.

Keywords: mirror finish, tribometer, ball-on-disk, scratch-test, SOG-layers

Industrial Tribology 1

Chair: Hector Torres

Thursday 12 June 2014 – 09.40-11.20

Room: Dania

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Three – body abrasion behavior of selected commercially available polymer materials

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The aim of this investigation was to examine several types of commercially available polymers for potential application in machine elements of conveyors or rotary feeders which are exposed to three body abrasion. Abrasion resistance of selected materials was evaluated on abrasion G 65 test rig with rubber and steel wheel setup, using the quartz sand (SiO_2) as an abrasive, with the average grain size of particles in range of 0.8 – 1.6 mm. Experiments have been performed under the dry conditions, and at room temperature, under the load of 50 N, with wheel rotation of 200 rpm, and testing time of 90 minutes. The best performing samples have been selected and further investigated on longer sliding distances, with corresponding testing times of 180, 270, and 360 minutes respectively. Results of testing on G65 test rig, as well as following surface topography analysis revealed the strong influence of polymer hardness and elasticity, as well as abrasive particle embedment on the wear behavior.

Keywords: abrasion, G 65, polymers, particle embedment

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New tribo-systems for sheet metal forming of advanced high strength steels and stainless steels

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Testing of new tribo-systems in sheet metal forming is nowadays an important issue, since new legislations push industry to replace current, hazardous ones. The present paper summarizes the work done in a PhD project at the Technical University of Denmark. The project focused on development of a new methodology for off-line testing of new tribo-systems for advanced high strength steels and stainless steels. The methodology is first presented and applied to an industrial case, where different tribo-systems are tested. For the purpose a new, Universal Sheet Tribotester was developed, which can run automatically, repetitive Bending Under Tension test. Tests on a lean duplex material reveal that the particular surface texture is very sensitive to hydrodynamic effects. The overall results show that the methodology ensures satisfactory agreement between laboratory and production tests, although disagreement can occur, if tribological conditions are not the same in both cases.

Keywords: tribo-system, galling

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Development of diffusion couple method to study chemical interactions between cemented carbide and difficult to machine materials

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In the present investigation, a diffusion couple method has been developed to study the chemical interactions between cemented carbide cutting tools and difficult to machine materials (Ferrous alloys, Ti and Ni based alloys). The method is relatively simple and consists of pressing a rod of the desired work material into the hole of a cemented carbide tool and further heating of the tool-work material couple in a high temperature furnace at 1100°C for 2 hours under inert gas atmosphere.
Polished cross sections of the diffusion couple specimens were investigated using different experimental techniques, including light optical microscopy (LOM), scanning electron microscopy (SEM), energy and wavelength dispersive spectroscopy (EDS/WDS) and electron back scattered diffraction (EBSD).
The results obtained indicate clearly that chemical interactions have occurred between the different alloys and the cemented carbide. In particular, the formation of a thick layer of titanium carbide was observed at the cemented carbide /Ti alloy interface while the formation of a distinct compound (η-phase) was observed at the cemented carbide /Fe alloy interface. The observed TiC-formation is supported by the small solubility range of carbon in bcc-Ti and the strong driving force for fcc-TiC_{1-x} formation even at low carbon contents. In the Fe-C system, the solubility of carbon in fcc-Fe stretches up to 8 mol% at 1100 °C, wherafter graphite is formed.

Keywords: cemented carbide, difficult alloys, diffusion couple, chemical interactions.

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Design of an axially concave pad profile for a large turbine tilting-pad bearing

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**Presenting Author: Nico Buchhorn*

To improve operational safety and/or achieve higher load capacity of large turbine tilting-pad bearings an axially concave pad profile is presented. The thermal and mechanical stress of the loaded pads of a test bearing in load between pads configuration has been analyzed in detail. The bearing with a double tilting support is lubricated by spray-bars and can be described by the following specifications: Five pads, 0.23 nominal preload, 60% offset, 56° pad arc angle, 500 mm inner diameter, 350 mm pad length and 1.28 per mille relative bearing clearance. Both film thickness and pressure distribution have been measured in a very high resolution. Pad temperatures are measured by the means of 100 thermocouples which are located 5 mm behind the sliding surface. The test procedure and test rig are described in detail. A fluid film calculation program in combination with a finite-element program is used to simulate the deformation of a single pad under high circumferential speeds. In this context, the axial and tangential heat transfer coefficients of the pad surface, which act as boundary conditions for the calculation of the 3D temperature distribution, are determined using an optimization process. Herein, the match of predicted and measured pad temperatures is the goal. It can be shown that there must be a huge difference in heat transfer in axial and tangential direction in order to match the large measured temperature gradient in circumferential direction. Based on the measured deformed profile the code is used to derive a concave pad profile, which will result in an axially non-arched sliding surface under the expected thermal load. Therefore, an iterative simulation procedure is used.

By decreasing the axial arching of the pad and thus the large film thickness at the axial ends using an improved profile designed for a specific operation point, the minimum film thickness and maximum pad temperature can be influenced beneficially. Hereby, either better operational safety or higher load capacity of the bearing can be achieved.

The comparison of measurement data and calculation results shows very good agreement regarding the pad deformations. The results indicate that by axially concave profiling of the loaded pads of a large tilting-pad bearing for a specific operation point, the static characteristics in the form of temperature, film thickness and load capacity can be improved.

Keywords: thermal deformation, compensation, tilting-pad, profiling

Lubrication 1

Chair: Peder Klit

Thursday 12 June 2014 – 09.40-11.20

Room: Nortvegia

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Adsorption of ATF additives on wet clutch friction interfaces under water contaminated lubricant conditions

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Stable friction and positive slope of friction-speed is the typical criterion for a good clutch performance. Lubricated friction interfaces used for wet clutches produces different friction behavior depending on the lubricant conditions. Usually the lubricant conditions vary for different automatic transmission fluid (ATF) formulations implying *e.g.* water contamination and these conditions might influence the deterioration of the clutch plates. The aim of this paper is to verify additive adsorption on friction interfaces and ageing of the friction material in wet clutch system for a water contaminated commercial ATF (DEXRON® VI). Standard clutch plates are employed in an automated wet clutch test rig to evaluate the friction characteristics of the tested lubricant. For controlled test conditions (speed, contact pressure, oil temperature) and specific number of test cycles, the mean friction coefficient and the friction vs. speed relations are monitored during sliding test. The resultant tribofilms on the tested friction interface surfaces are characterized by means of Scanning Electron Microscopy-Energy Dispersive X-ray spectroscopy (SEM- EDS), Attenuated Total Reflectance -Fourier Transform Infrared Spectroscopy (ATR-FTIR) and X-ray Photoelectron Spectroscopy (XPS analysis). The spectroscopic techniques were used to analyse adsorbed additives on friction interfaces and made it possible to correlate measured data to the specific friction behavior obtained after water contamination of the ATF.

Keywords: Wet clutch, water contamination, ATF, additive, surface analysis.

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The viscosity of Dimethyl Ether (DME) determined by Quartz Crystal Micro-balance (QCM)

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Dimethyl Ether is known as a green fuel capable of giving high efficiency to diesel engines without forming particulate matter in the exhaust [1]. While the combustion qualities of this fuel are excellent, its low lubricity [2] and viscosity [3] cause the fuel injection equipment to break down prematurely due to wear. A minor drawback is the low boiling point of the fuel which implies pressurisation to obtain a liquid.

The viscosity of DME at the vapour pressure has been determined [3] but in the diesel engine the fuel is pressurised to 40-50 bar before the high-pressure pump brings it to 300 bars. These pressure levels are though interesting for the lubrication of the injection equipment.

Pressurising DME with different gases seems to alter the viscosity of the fuel. This has been visually observed at the Shell Eco Marathon in France in 2004 but no direct measurement of this phenomenon has been conducted.

The present work uses a Quartz Crystal Micro-balance (QCM) to measure the viscosity of DME at different pressures. The QCM is a small crystal used for weighing e.g. molecules as its frequency is dependent on the mass adsorbed to the surfaces. The viscosity of a surrounding liquid also affects the frequency so the QCM can be used to characterise this property.

A series of viscosity measurements are performed both to establish the pressure-viscosity coefficient of DME and to characterise the effect of gases on the viscosity of DME as a function of the pressure. It appears that there is a significant difference in the viscosity of DME when helium and nitrogen are used. The experimental results are analysed and a tentative model is derived. The results have a significant impact on the use of DME in diesel engines as pressurisation with an optimised gas composition could reduce the lubricity challenge of this green fuel.

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3. *Sivebaek, I.M., Sorenson S.C., Jakobsen J. "Dimethyl Ether (DME) – Assessment of Viscosity Using the New Volatile Fuel Viscometer (VFVM)" SAE* Paper 2001-01-2013. 2001.*

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Characterization of start-stop motions – a novel approach

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1. Introduction

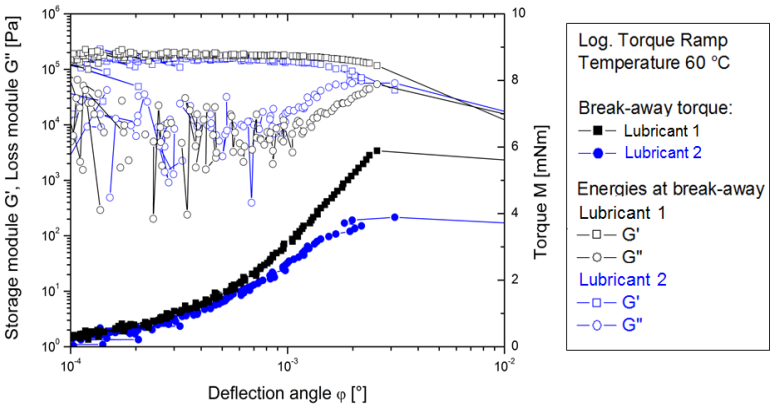
Critical aspects of tribological system like start-stop motions or stick-slip properties are characterized by mechanisms that take place in the regime between static and dynamic friction. Measurements at extremely low speeds are necessary to look at these phenomena in detail, to investigate the nature of the phenomena.

2. Approach

Rheometers are optimized for controlling precise movements (min. deflection angles 0.1 µrad, resolution 10 nrad) and torques (min. torque: 10 nNm, resolution: 0.1 nNm) and for measuring the reaction movement or the reaction torque. This precision allows for the characterization of the transition from static to dynamic friction.

In Rheology, the transition from static to dynamics, the determination of yield and flow point, is characterized by the so called amplitude sweep. At a constant frequency, deflection is induced in the sample through sinusoidal motion. The reaction of the sample is measured and from the phase shift and changes in amplitude, the storage (G') and loss (G'') moduli can be calculated. These hold information about the stored (elastic) and dissipated (viscous) properties of the characterized system. This approach is transferred to tribo-systems.

3. Results



Depending on the lubricant, different transition patterns can be differentiated, including information pertaining to the ratio between elastic and dissipated energy. Lubricant 2 shows a smooth transition from static to dynamic friction. Lubricant 1 breaks free abruptly. Break away torque and deflection angle can be determined from the measurements. Details of the method, its scope and limitations, will be discussed here.

Figure 1: Storage and Loss modulus, and Torque as a function of deflection angle of a lubricated tribo-contact between steel and steel

Keywords: tribology of materials, friction, lubrication, tribological testing

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Feedback-Controlled Lubrication for Reducing the Lateral Vibration of Flexible Rotors supported by Tilting-Pad Journal Bearings

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Fluid film journal bearings are well known machine elements with a long history of development and improvement. Such a history turned them into a standardized element which can be easily specified within the designing process of new machines. Nevertheless, due to the continuous requirements of higher efficiency performance for rotating machines, there is still space for further improvements. In such a framework, Tilting-Pad Journal Bearings (TPJBs) – well known type of fluid film bearing – have naturally evolved to mechatronic machine elements by means of the addition of electromechanical components which enable them to adjust their behaviour to new conditions and requirements. TPJBs with electronic radial oil injection or actively-lubricated TPJBs or simply active TPJB are provided with hydraulic actuators such as servovalves, which connected to a high pressure supply unit can inject pressurized lubricant into the bearing clearance through orifices commonly machined in the middle of the pad surface. For these mechatronic machine elements, digital control systems govern the servovalves, regulating the lubricant injection flow and hence the pressure distribution composed of hydrodynamic and hydrostatic effects. As a result, the bearing stiffness and damping properties are modified depending on control signals. Different lubrication regimes can be featured depending on whether the control laws are used or not and also depending on the type of controllers used. For surely enhance the system dynamic performance of rotating machines, a feedback-controlled regime must be implemented, referred here as an active lubrication regime.

In this work, the feedback-controlled lubrication regime is studied and experimentally tested, based on a proportional-integral-derivative (PID) controller. A model-free approach was used to design and built the controller. For synthesizing the controller gains, special focus is given to the problem of reducing the system lateral vibration around its equilibrium position in a wide excitation frequency range. With such a lubrication regime, the resulting pressure distribution over the pads is dynamically modified by using the servovalves as actuators and the lateral movements of the flexible rotor as feedback control signals. The lateral dynamics of a large overhung centrifugal compressor is resembled by a test rig designed with such a goal. The flexible rotor is supported by an active TPJB provided with two high-frequency response servovalves. The rotor-bearing system is capable to operate under three different lubrication regimes, namely a) the conventional or passive lubrication regime, dominated by the hydrodynamic effect, b) the hybrid or adjustable lubrication regime, built up on the hydrodynamic and hydrostatic effects, and c) the feedback-controlled or active lubrication regime for which the hydrostatic contribution to the pressure field is controlled by well-tuned control gains.

The main contribution of this work is to demonstrate the enhancement of the dynamic properties of a flexible rotor-bearing system supported by active TPJB by means of the feedback-controlled lubrication regime via PID-controller, whose gains are synthesized from a model-free control design approach. Good experimental results are obtained, and a significant improvement of the rotor-bearing system dynamic performance can be experimentally demonstrated in a wide frequency range, when feedback-controlled lubrication regime is used.

Keywords: Tilting-pad Journal Bearing, Mechatronic machine element, Feedback-controlled lubrication.

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Tribofilms of MoS_2 nanotubes on steel and DLC-coated surfaces

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MoS_2 and WS_2 solid-lubricant nanoparticles as additives in oil provide good tribological properties based on the physical lubrication mechanisms in the contact. Therefore, they are strong candidates for use in the lubrication of DLC coatings, which only poorly interact with the traditional, chemically based additives. But until recently, attempts of lubrication of the DLC coatings with oils containing nanoparticles have been very scarce and thus the understanding of the interactions of the nanoparticles with the diamond-like carbon (DLC) coatings remained limited. We showed that the use of MoS_2 nanotubes in oil can provide very effective lubrication for the steel and also for the DLC coatings, in spite of their lower chemical reactivity. Furthermore, formation of a tribofilm from the solid nanoparticles is decisive for their beneficial performance with both types of surfaces. We studied how a tribofilm formed from the MoS_2 nanotubes is related to the tribological properties of these nanotubes and we analysed such a tribofilm on steel and DLC-coated surfaces using SEM, EDS, XPS and AES to observe any differences in the structure and interactions of the tribofilm with steel and DLC coating. The major difference between the steel and the DLC contacts is that the MoS_2-based tribofilm surface coverage is greater in the case of the steel/steel contacts compared to the DLC/DLC contacts. Nevertheless, no direct evidence of any chemical reactions between the MoS_2 and the steel or DLC coating was observed and we found that the chemical and functional properties of the MoS_2-based tribofilm are very similar, or even the same, for both the steel and DLC-coated surfaces.

Keywords: MoS_2 nanotubes; Tribofilm; DLC; steel; XPS

Coatings 2

Chair: Albano Cavaleiro

Thursday 12 June 2014 – 12.00-13.00

Room: Suecia

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Integration of HiPIMS Equipment into an Industrial Coating Production for Cutting Tools

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HiPIMS coatings are rapidly gaining ground for cutting tool applications due to advantages such as smooth, droplet free coatings with superb adhesion and perfect homogeneity all around the tool geometry. Hence, more and more cutting tool producers are in the process of integrating HiPIMS coating machines into their production.

This paper will discuss the full process chain of an industrial coating production – starting with jigging, surface and cutting edge preparing, cleaning, coating and finishing operation – dedicated to the HiPIMS coating process. Advances of the HiPIMS deposition equipment will be presented as well as specific modifications of the auxiliary processes prior and after coating.

A novel AlTiSiN film deposited with HiPIMS will be presented as a model system for all the steps of a commercial coating production. The evaluation will include film characterisation and recent cutting test results.

Keywords: HiPIMS, sputtering, cutting tools

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Characterisation of Nanocomposite Ti-C-N Coatings Deposited by Industrial-Scale DC Magnetron Sputtering for Tribological Applications

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Amorphous carbon is well-known for its low friction due to its self-lubricating behaviour. By combining amorphous carbon with hard nanocrystallites, nanocomposite coatings with low friction, high hardness and improved fracture toughness may be obtained. In this work, nanocomposite coatings consisting of Ti(C,N) nanocrystallites embedded in an amorphous carbon-based matrix were studied. The coatings were deposited at an elevated temperature of ~370 °C by reactive DC magnetron sputtering using an industrial-scale CemeCon deposition system. A mixture of Ar and N_2 was used in combination with a graphite and a titanium target. Keeping the working pressure constant, the N_2-fraction in the sputter gas was varied in order to study its impact on the microstructure and the mechanical and tribological properties of the coatings. The microstructure of the nanocomposite coatings was evaluated using XRD, XPS, TEM and Raman spectroscopy. It was found that the highest amount of crystalline material was obtained at the lowest N_2-fractions, where the highest concentration of titanium was likewise observed by RBS. Depending on the N_2-fraction in the sputter gas, nanoindentation revealed hardness values exceeding 20 GPa, whereas compressive stresses of 0.8 GPa to 2.8 GPa were determined from substrate bending. Finally, the tribological performance of the coatings was evaluated in a pin-on-disc test. It was found that the wear rate was sensitive to the relative content of amorphous and nanocrystalline material, whereas the friction coefficient against alumina was essentially unchanged.

Keywords: nanocomposite; microstructure; mechanical properties; pin-on-disc; amorphous carbon

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The effect of V additions on the tribological behaviour of sputtered TiSi(V)N coatings at room temperature

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TiSiN hard coatings are well established in commercial tribological applications such as high speed cutting and dry machining processes due to their excellent oxidation, and extremely high hardness. However, their friction coefficient revealed to be fairly high. Therefore, a lot of efforts has been carried out in the last years to develop self-lubricant coatings, that retains the good properties of the common ternary (TiX)N films (X = B, Cr, Al, Si, Cr, C, etc) and offers lubricity through the formation of low-friction oxides. Magnéli phase oxides have attracted the scientific community attention, particularly those formed in vanadium containing coatings. The beneficial influence of Magnéli oxides formed by oxidation of vanadium has already been reported by several researchers; however, in ternary systems they only have considered the effect of V dopping on CrAlN and TiAlN coatings in single layer or multilayered configurations. Thus, the aim of this investigation was to study the effect of V content on the tribological behaviour of Ti-Si-V-N coatings deposited by DC reactive magnetron sputtering. Comparison of these results with those achieved for TiN, and TiSiN coatings prepared as references is also provided. The tribological properties of coatings were evaluated at room temperature in pin-on-disc wear equipment, using as counterparts Al_2O_3 and HSS balls. After wear tests, the wear tracks and wear debris were characterized by scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) and Raman spectroscopy. V additions successfully decreased the wear rate and the friction coefficient of TiSiN coatings, due to V_2O_5 oxide formation. When Al_2O_3 balls were used as counterparts the wear rate and friction coefficient of coatings are much lower than when sliding against HSS steel balls. TiSiN displayed the lowest wear resistance among all the tested coatings. The wear of V rich coatings was driven by polishing wear when tested against Al2O3 balls, whilst adhesion wear took place when tested against HSS balls.

Keywords: TiSi(V)N coatings, Tribology, Wear, Magnéli oxides

Polymer 1

Chair: Ion Marius Sivebæk

Thursday 12 June 2014 – 11.40-13.00

Room: Dania

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The impact of the standard turbine oil and the biodegradable synthethic oil on properties of the polymers used as sliding layers in the hydrodynamic thrust bearings.

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Gdansk University of Technology, Faculty of Mechanical Engineering

The polymers used as sliding layers in hydrodynamic thrust bearings are exposed to severe conditions: relatively high temperature, high pressure and sheering of the fluid film.

The results of investigations on the impact of the fluid film conditions on the mechanical and the tribological properties of thermoplastics used as sliding layers will be presented in the paper. Standard turbine oil ISO VG 32 and biodegradable synthetic oil were used in the tests. Although the oils are used for lubrications of the polymers, there are realatively few information about their impact on the thermoplastics.n The polymers used in the tests were selected due to their industrial applications in the hydrodynamic bearings. Composite based on PTFE and PEEK as well pure PTFE, PEEK, UHMWPE and PVDF were tested.

Two factors (temperature of oil and pressure of oil) have been taken into account. The research showed that exposure to high temperature (100°C) in the oil, caused the change of the elastic modulus of the material. The other properties as for example thermal stability also changed after exposure to both types of oil irrespective of conditions of immersing.

Keywords: polymers, standard turbine oil, biodegradable synthetic oil

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Friction and wear studies of some PEEK materials

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Replacing conventional steel by polymer composite materials is one way to achieve lightweight and lubricant-free machine components. Mechanical strength and thermal properties are two major criteria for the application and selection of polymer materials in high performance industrial systems. Depending on actual application a compromise between mechanical and thermal properties often needs to be considered within the tolerance boundary in order to obtain optimized results.

In this study the tribological performance of some PEEK (polyether ether ketone) polymers, both pure and carbon fibre filled materials, are experimentally evaluated. A reciprocating sliding laboratory test with a steel ball against polymer disc geometry was used. The effects of contact load, number of cycles, temperature, and surface roughness of the steel counter surface, on friction and polymer wear are investigated. The thermoplastic PEEK was selected due to its high strength properties at elevated temperatures.

The long-term aim of the study is to evaluate the possibilities and limitations for using polymer materials in tribological contacts, e.g. in a polymer/steel spur gear pair. Therefore, modelling of the gear mesh and analysis of the contact forces and heat generated in the gear tooth is also included in this study.

This study suggests a guideline of materials selection, while gear design such will not be discussed. Different tribology test conditions showed very different friction level and wear behaviour. The implications of these tribology test results on the modelling results and the function of a possible application are discussed.

Keywords: PEEK, friction, wear, FEM

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Tribological behaviour of peek/MoS_2 composites: Influence of MoS_2 particles concentration and processing temperature

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The use of high-resistant polymers is becoming more and more interesting from tribological, mechanical, manufacturing and economical point of view. Poly-ether-ether-ketone (PEEK) is a high-resistant polymer with high melting temperature, good mechanical and promising tribological properties. The increasing use of PEEK for different applications showed a need for PEEK material (and its composites) to withstand severe contact conditions, such as non-lubricated contacts. PEEK's relatively high coefficient of friction in dry contacts (≈0,4-0,6) intensified a need for further improvement of its tribological properties, especially lowering coefficient of friction which can be achieved by incorporating self-lubricated particles such as Molybdenum disulphide (MoS_2). The use of conventional manufacturing procedures, such as injection molding and extrusion, limit researches and manufacturers to the material melting properties. By using non-conventional procedures, processing temperatures can be varied and their affect can be studied.

In this study, coefficient of friction, wear rate and wear mechanisms of PEEK/MoS_2 composites are presented, in a relationship to MoS_2 particles concentration (0 – 10 wt.%) and processing temperature (300 – 350 °C). Tribological tests were performed by reciprocating sliding in dry conditions with steel pin as a counter-material. Results show that processing temperature has a considerable influence on tribological and mechanical properties while MoS_2 particle concentration have only minor effect onto the tribological behaviour.

Keywords: polymer composites, friction, wear, processing temperature, PEEK, MoS_2

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Low Wear of Carbon Fiber Filled PTFE in Gaseous Hydrogen

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A fuel cell vehicle (FCV) is expected as an ultimate environment-friendly transportation system since it can travel without fossil fuel consumption and greenhouse gas emissions by using hydrogen as a fuel. For the current generation of FCV, which is using 70 MPa high-pressure hydrogen gas to get a long cruising distance as gasoline engine vehicles, hydrogen gas should be pressurized up to 100 MPa and stored in hydrogen fuelling stations. Therefore, improvements in the performance and cost efficiency of high-pressure gas compressors are important tasks for establishing successful hydrogen infrastructure.

Authors have been examined tribological performance of various kinds of polymer composites in gaseous hydrogen to find the ideal composition of polymer sealing material for high-pressure hydrogen gas applications. In this study, we would like to report some friction and wear measurement results of carbon fiber filled polytetrafluoroethylene (PTFE) in hydrogen gas, since the PTFE composite filled with 15 wt% pitch-based carbon fiber showed characteristics low wear behavior in gaseous hydrogen under the sliding speed of 2 m/s and contact pressures from 1 MPa to 3 MPa. To understand the low wear mechanism in hydrogen, detailed analyses for chemical composition and structure of polymer transfer film formed on the sliding counterface, 440C martensitic stainless steel, were conducted after sliding tests by using XPS, Raman microscopy and imaging FT-IR. Results of surface analyses indicated that a smooth and homogeneous polymer transfer film composed of PTFE and carbon was formed on the metal counterface only in hydrogen, which might be preventing further material adhesion from the composite surface and reduce the wear amount.

Keywords: carbon fiber filled PTFE, hydrogen, seal, friction, wear

Lubrication 2

Chair: Mathew Mate

Thursday 12 June 2014 - 11.40-13.00

Room: Nortvegia

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Lubricating properties of MR fluid

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Magneto-rheological (MR) fluids are obtained by dispersing ferri-magnetic particles (e.g., carbonyl iron particles) in oil. The viscosity of MR fluids is dramatically changed in a magnetic field and the change is reversible. The response of the change depends on magnitude of a magnetic field, and the scale of the response speed is in milliseconds. From this characteristic, MR fluids are expected as new hydraulic oil applied for dampers, actuators and brakes. However, lubrication properties of the MR fluids were inferior to that of conventional oil because of the component particles in the MR fluids. Accordingly, if lubricating properties of MR fluids will be improved, it is possible to extend their application field. For that reason, the objective of this research is to investigate the lubricity of the MR fluids focusing on the particle size.

The sliding tests were conducted by using a cylinder on disk type reciprocating sliding tester (SRV1, Optimol) and the test condition is listed in Table 1. Disk and cylinder specimens were made of AISI 1010 and AISI 52100, respectively. For the lubricants, Base oil and three types of MR fluids: Fine (Average particle size ϕ2 μm), Medium (ϕ4 μm), and Coarse (ϕ8 μm) were used. Surface profile was measured by surface roughness tester (SURFCOM 1500SD3-12, ACCRETECH).

The friction behavior is shown in Fig. 1. The result shows that all MR fluids show higher friction coefficients than the base oil at the end of the test. However, during the term from 1000 to 2000 sec, the friction coefficient of Fine is lower compared with than that of Base oil. Maximum wear depth of disk specimens in sliding surface is shown in Fig. 2. The Fine case shows the lowest wear depth in all lubricants. Focusing on the influence of particle behavior on lubricating properties of MR fluids, the particle motion is investigated and discussed by in-situ observation using a high speed camera.

Table 1 Test condition

Temperature	30 °C
Amplitude	1 mm
Frequency	50 Hz
Load	20 N
Time	60 min.

Fig. 1 Friction behavior of each lubricant

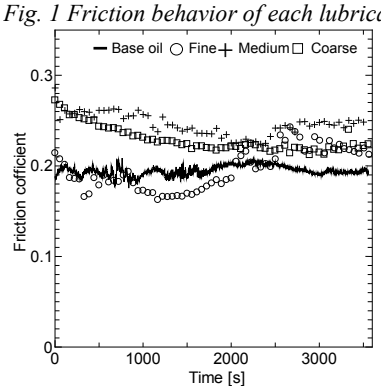
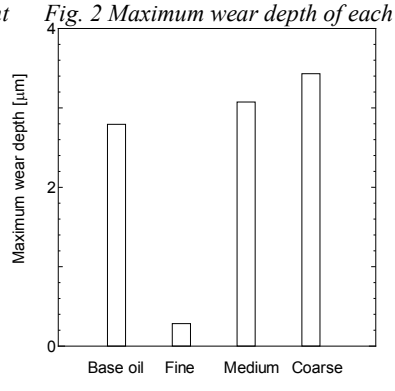


Fig. 2 Maximum wear depth of each lubricant



Keywords: MR fluids, friction, wear, particle, in-situ observation

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EHL Traction Analysis of Perfluoropolyether Fluids Based on Bulk Modulus

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Perfluoropolyether (PFPE) fluid are used in magnetic recording media, aerospace industry and satellite instruments satisfactorily. Recently these oils have been introduced as hydraulic fluids, high temperature liquid lubricants in turbine engines and base oils of high-temperature greases. Despite considerable research on PFPE, the rheological characteristics at high pressure and EHL traction have not been understood yet.

High pressure density measurements of these three kinds of commercial PFPE fluids (Krytox, Demnum and Fomblin) were done at temperatures from 293K to 333K and pressure up to 1.2 GPa. The tangent bulk modulus - pressure - temperature relation and secant bulk modulus - pressure - temperature relation of PFPE fluids were proposed based on the free volume and the phase diagram.

The traction coefficient was also measured using a ball on disk machine. It was found that the maximum traction coefficient and the limiting shear stress are closely related to the tangent bulk modulus and the secant bulk modulus, respectively. That is, the traction characteristics are mainly influenced by the bulk modulus of the oil.

Keywords: PFPE fluid, rheology, bulk modulus, traction, EHL

EHL for lubricated contacts of DLC – role of interfacial and contact properties

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Preference of presentation: Oral

Keywords: DLC, EHD lubrication, solid-liquid interface

Abstract

Tailoring friction properties of lubricated contacts operating under EHD lubrication regime came in the recent years in the forefront, especially in terms of reducing viscous friction that govern friction performance of those contacts. Several studies in past several years [1-4] showed potential perspective effect of reducing coefficient of friction of lubricated contacts in EHL when using DLC coatings and different models that explain reduction in coefficient of friction were proposed. In our recent study [2] we introduced "Slip inducing interaction model based on surface forces" that explain DLC-oil slip on terms of surface forces and connects this phenomenon with reduced coefficient of friction in EHL.

With this study we upgrade our previous results. Series of test were performed, by using different types of DLC coatings deposited on surfaces with different roughness, using two different types of lubricants and tested with variation contact properties (load, slide-to-roll ratio). Results show that important role in tailoring friction properties of lubricated contacts in EHL in addition to surface properties, such as roughness, wetting and surface energy, play also contact conditions and selection of the lubricant. We also show that relative surface speed is the important parameter that influence on friction properties for steel-mated contacts of DLC.

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Overcoming starvation in EHL point contacts by enhanced replenishment

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An innovative approach for enhancing replenishment in starved EHL contacts is introduced in this paper. An external restriction (frictionless slider) is used to create a forced hydrodynamic channelling of lubricant towards the rolled track. The hydrodynamic entrainment induced by the slider leads to recover the displaced lubricant and enriching the depleted track. Measurements have been carried out by a Tribometer equipped for measuring friction and film thickness simultaneously. The results showed a significant reduction of friction after introducing the mechanism of induced replenishment even with a very little amount of lubricant available on the track. Measurements of film thickness showed that the severely starved EHL contacts transform completely to the flooded regime, indeed the film thickness has been doubled many times, after applying the channelling by the slider even under extreme operating conditions. Otherwise, the performance of this approach was assessed over time by measuring friction and film thickness simultaneously and it was found that the mechanism of channelling lubricant was stable and reliable in generating induced replenishment. Therefore, the mechanism can be easily integrated in some industrial applications such as rolling bearings to overcome the phenomenon of starvation.

Keywords: starvation, replenishment, EHL, friction, film thickness.

Coatings 3

Chair: Nuria Espallargas

Thursday 12 June 2014 – 14.00-15.20

Room: Suecia

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On the low friction of W-S-N coatings

***Jill Sundberg*[1], *Harald Nyberg*[2], *Erik Särhammar*[3], *Tomas Nyberg*[3], *Staffan Jacobson*[2], *Ulf Jansson*[1]**

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Tungsten disulphide, WS_2, is a material with a highly anisotropic, layered structure. The chemical bonds between layers are weak, and so the layers are easily sheared, making WS_2 an excellent intrinsic solid lubricant. It can be used as an additive in liquid lubricants and greases, but also as a coating, so that the surface itself is modified to have low-friction properties. A convenient method to deposit WS_2 is by magnetron sputtering. Sputtered WS_2 coatings exhibit very low friction levels in dry conditions, but they are often porous, soft and subject to wear. One way to improve the mechanical properties is the addition of other elements, which favours the formation of denser coatings with smaller crystallites. During tribological contact a tribofilm of, crystalline WS_2, with the easy shear planes aligned along the sliding direction, is formed on the outermost surface, which gives low friction. This has been shown for a number of elements, both non-metals such as C and N, and metals such as Ti and Cr. An important consideration, however, is that the added element(s) should not disturb the tribofilm formation.

In this study, W-S-N coatings were deposited by reactive magnetron sputtering from a WS_2 target and N_2 gas. A series of coatings with increasing N content was obtained, which have been characterized with respect to their elemental composition and chemical bonding, their structure and morphology, and their mechanical properties. The coatings were tribologically tested in a ball-on-disc setup with reciprocating geometry, using a steel ball as counter-surface. Tests were performed in atmospheres of N_2, dry air, and humid (ambient) air. In N_2, extremely low and stable friction levels (μ=0.01-0.04) were observed for all coatings. In dehumidified air, containing O_2, the friction levels were higher (μ=0.06-0.3), with the lowest level observed for the coating with the lowest N content, and then increasing with the N content. In humid air, containing H_2O as well as O_2, the friction levels were higher and in some cases lead to failure. The wear of the coatings was measured, and low friction levels were found to correspond to low wear rates, down to 50 $\mu m^3/Nm$. A pure W-S coating, however, displayed similar friction levels but higher wear, due to its porosity and low hardness. The wear tracks on the coatings and the wear marks on the steel balls were studied by Raman spectroscopy in mapping mode, which revealed the presence of WS_2, but also of tungsten oxides and carbon. In this study, the friction and wear of the W-S-N coatings in the various environments are related to the structure and chemistry of the coatings, and the composition of the tribofilms and wear debris formed.

Keywords: WS_2, coatings, reactive sputtering, unlubricated sliding, tribofilm

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Enhanced contact fatigue behavior of coated tool steel by using W-C:H thin film

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Susceptibility of coated tool steels to mechanical degradation associated with repetitive contact loading has been shown in previous work. The influence of tool steels microstructure was evidenced by consideration of thin film detachment as critical damage mechanism. In this regard, delamination process was related with cracks nucleated on primary carbides which propagate radially through the metal matrix. Thus, finer and tougher, as well as less irregular and more homogeneously distributed primary carbides were pointed out as key microstructural features for enhancing contact fatigue response of coated cold-work tool steels. However, properties of TiN coating were also important on fatigue contact response, where microdroplets were critical defects to induce decohesion mechanisms. Specifically, when steels processed by conventional casting and forging route were used as substrates.

Taking into account all these factors, the main objective of present study is to evaluate the contact fatigue behavior of a metal containing diamond-like carbon coating (W-C:H), with low friction and enhanced surface roughness, deposited on wrought cold work tool steel (Universal). Chemical composition, microstructure and mechanical properties of thin film and substrate are described. Spherical indentation technique is used to evaluate the contact behavior under monotonic and cyclic loading conditions.

Although W-C:H coating experienced premature fracture under monotonic loads, delamination do not appear under cyclic loading conditions even when a load of 800 N was applied during 10^6 cycles. At this cyclic loading condition, TiN coating was detached from Universal steel substrate. Cross-section analysis exhibited that subsurface cracks nucleated on primary carbides are connected with thin film cracks. However, buckling damage was not discerned at interface coating/substrate. Local graphitization and surface free of droplets are pointed out as the main enhancing factors to contact response.

Keywords: Contact fatigue, spherical indentation, W-C:H coating

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Performance of WS_2-based coatings under lubricated sliding

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Transition metal dichalcogenides (TMDs), such as MoS_2 and WS_2, are well known intrinsic solid lubricants. Their low-friction properties are due to the layered crystallographic structure of the materials, where the shear strength along the layers is very low, facilitating sliding with low resistance. PVD coatings based on tungsten disulphide have been investigated in a number of studies, where they have shown very promising results in terms of friction and wear, particularly in unlubricated sliding in low humidity conditions. The best wear properties are observed for alloyed coatings, where a third element (C, N, Cr, Ti etc.) is added to the WS_2 coatings. The benefit of adding the third element is mainly that it reduces the crystallinity of the deposited films, which leads to increased hardness, since the number of easily sheared crystallographic planes is reduced. For such poorly crystalline or amorphous coatings, low friction is still observed, and is still due to sliding in easily sheared planes of the WS_2 crystal. However, here the WS_2 crystals are formed during sliding, within the tribofilms found on the contacting surfaces.

Due to their intrinsic low friction properties, combined with good wear resistance, WS_2-based coatings are an interesting option for coating of machine elements that sometimes operate under poor lubrication. The tribological properties of WS_2-based coatings have been characterised under various conditions, but almost exclusively without lubrication. Their performance in lubricated sliding is therefore mostly unknown, and requires attention before they can be considered for lubricated applications.

This work deals with the lubricated sliding behaviour of a number of WS_2-based coatings, which have shown promising properties in unlubricated sliding in previous studies. The coatings include pure WS_2, as well as W-S-C, W-S-N and W-S-C-Ti coatings, all produced by magnetron sputtering (reactive or non-reactive). The coatings are tested in a reciprocating sliding rig, lubricated with pure base oil (PAO), and are evaluated in terms of friction and wear. The influence of lubrication on the formation and composition of the tribofilms on the coatings and counter-surfaces are also studied, with special emphasis on the oxidation of the tribofilms, since the presence of humidity and oxygen is known to have a large impact on their tribological performance.

Keywords: TMD, WS_2, component coatings, low friction, lubrication

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The effects of aging and elevated temperatures on of DLC films

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Presenting author: Helena Ronkainen

Diamond-like carbon (DLC) films cover a wide range of different carbon based coatings, starting from soft hydrogenated films to extremely hard hydrogen-free films. Due to the varying characteristics of DLC coatings, they have differing tribological properties that influence on their performance and applicability. Coating properties, such as elasticity and fracture toughness, greatly influence on the practical performance of the coatings in real applications. An interesting aspect is also the influence of tempering or aging of the coating on the performance.

In order to study how aging influences the tribological performance of DLC coatings we have evaluated 20 years old DLC coatings and compared the results to earlier results reported. It seems that the effect on the wear resistance has not changed greatly. However, variation in the friction performance for the a-C:H type coatings was observed. When studying the temperature effects on a-C:H type DLC coatings similar type of effects were observed. These aging and temperature effects were further elaborated by multi-scale modeling. In multiscale modelling the integrated approach combining material microstructural features modelled by molecular dynamic simulation (MDS) on nanoscale with FE modeling was applied. The tribological aspects of aging and elevated temperatures on DLC films will be reviewed with the validation of the models in different scaled and the arguments for aging mechanisms are presented.

Keywords: DLC, a-C:H, ta-C, tribo-performance, aging, elevated temperature, modeling.

Polymer 2

Chair: Yoshinori Sawae

Thursday 12 June 2014 – 14.00-15.20

Room: Dania

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An unconventional approach in polymer wear: Online vision system

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Tribology which deals with the fundamental interaction of materials has robust link with morphological modification of contacting surfaces. Hence, adequate information on surface modification is essential for an effectual design of tribological system. Amongst different existing materials, polymer-metal pairs are commonly used in bearings, rollers and gears. Tribological interaction of this tribo-pair requires ample understanding of its surface responses. Generally, these surfaces are studied using traditional post-mortem analysis based on macro- and micrographs (qualitative), and roughness (quantitative) changes. These conventional techniques do not capture critical information such as "evolution" of morphological features. Nevertheless, with the recent advancements in electronic imaging, the morphological changes of moving surface are studied in real-time at a micro scale. In our investigation, a polymer-metal pair is studied for its surface evolution under Hertzian line contact using a high speed online vision system. The acquired real time images are segmented and processed in order to segregate the surface scars produced by wear mechanisms such as abrasion, adhesion and fibre damage. The quantitative estimate of these surface scars from the segmented images represents an evolution curve of surface morphology. Furthermore, the online vision monitoring reveals that the conformal contact has been established through breaking of asperities followed by plastic flow of polymers. Once, after achieving the conformity in contact surfaces at the steady stage, dynamic mechanisms such as back transfer of polymers from steel surface and plastic flow are observed for obtaining a clear understanding of the wear process. Additionally, the blur of the acquired images due to the wear process serves as a quantitative estimate for wear. The evolution curves together with friction, wear, and temperature response provides complete understanding of the tribological process. This combined information can be beneficial for material designers and maintenance engineers for new material design and condition monitoring respectively.

Keywords: Online vision system, polymer wear, quantitative micrography

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Erosion wear of glass fibre reinforced vinylester

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* Presenting author

Glass fibre reinforced vinylester composites are widely used in tanks, piping, ducts, and fans in demanding applications, such as waste water treatment plants, chemical processing, and pulp and paper manufacturing due to their excellent chemical resistance and mechanical performance. In addition to corrosive environments, materials are exposed to erosion wear and high temperatures (close to 100°C) in many hydrometallurgical processes. However, there is limited understanding on the erosion wear of vinylester based composites and therefore knowledge should be gained on this field in order to evaluate their long-term behaviour and optimize the maintenance intervals of different structures in various wear conditions.

This study evaluates the erosion wear of glass fibre reinforced vinylester composites (FRP) using a high speed slurry-pot type wear tester. The wear rates of FRP were also compared using different abrasives, namely quartz, copper ore, chromite, zinc concentrate, and tailings. Furthermore, the effect of particle size and the abrasive concentration on the FRP wear was studied. The erosion wear results of FRP were compared to different rubbers, such as natural rubber (NR) and bromobutyl rubber (BIIR) as well as few common thermoplastics, such as polypropylene (PP) and polyvinyl chloride (PVC), which are potential sensor, gauge, lining, and other wear resistant part materials in hydrometallurgical reactors.

The results show that coarse quartz produces the largest wear rates on FRP samples, while zinc concentrate shows the lowest wear. Minor changes in the abrasive particle size have no effect on the wear results: similar wear rates were obtained with fine quartz grades with the particle size varying between 75-100, 100-125, or 125-185 μm. Only when the particle size was increased to 300-600 μm, wear rates were markedly increased. When comparing the wear rates of different materials, it can be concluded that with all abrasive types, tested rubbers and thermoplastics have lower wear rates than FRP.

Keywords: erosion wear, FRP, glass fibre, vinylester composite

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The Wear and Thermal Mechanical contact Behaviour of Polymer Gears

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Presenting author: Dr. Ken Mao

The present paper will concentrate on the extensive investigation of polymer composite gear wear and thermal mechanical contact behaviour. A test method for polymer composite gear wear has been proposed in the current paper and extensive investigations on polymer composite gear wear have been carried out.

It has been found from the tests that the polymer gear wear rate will be increased dramatically when the load reaches a critical value for a specific geometry. The gear surface will wear slowly with a low specific wear rate if the gear is loaded below the critical one. The possible reason of the sudden increase in wear rate is due to the gear operating temperature reaching the material melting point under the critical load condition. Gear surface temperature has been then investigated in detail through three components: ambient, bulk and flash temperatures. Through extensive experimental investigations and modelling on gear surface temperature variations, a general relation has been built up between gear surface temperature and gear load capacity. The method has been related to test results under different operating ambient temperature and gear geometries. Good agreement has been achieved between the proposed method predictions and experimental test results.

Keywords: wear, polymer gear, specific wear rate.

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Wear resistance of polymeric materials based on PBT

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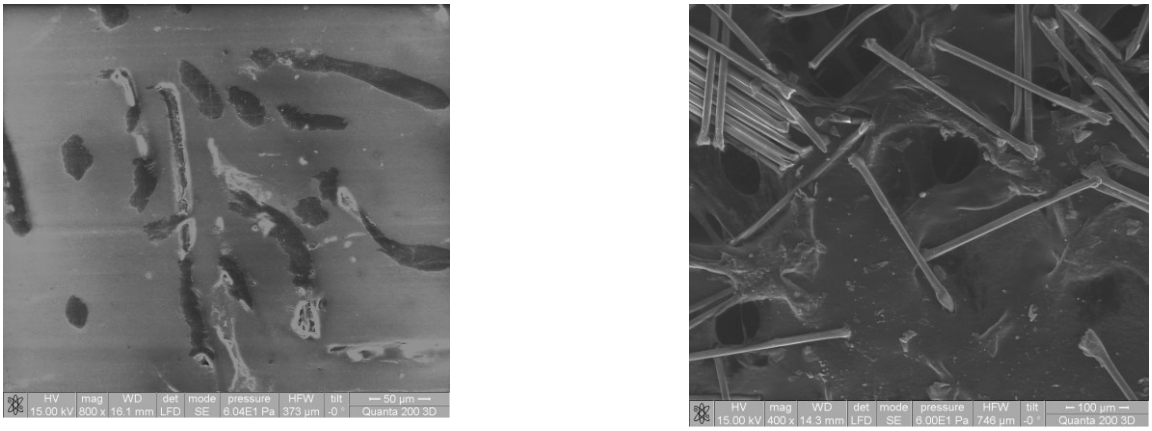
Abstract
This paper presents the tribological behavior of four polymeric materials, polybutylene terephthalate (PBT), PBT +10% micro glass beads, PBT + 10% polytetrafluoroethylene (PTFE) and PBT + 10% aramidic fibers, in order to rank them in dry regime. Tests were done using a block-on-ring module (tribometer CETR®). The test parameters were: sliding speed (0.25 m/s, 0.50 m/s and 0.75 m/s), the load and the sliding distance being kept constant (5 N and 10 N and 5000 m, respectively). There were analyzed the dependence of friction coefficient and linear wear rate on the adding material. Particular wear mechanisms were identified with the help of SEM images.



Polyamide with 10% aramid fiber, F=10 N, v=0.75 m/s Aramid fibers before adding into PBT

Fig. 1. SEM images of the tested materials

The tested materials they were obtained by molding at ICEFS Savinesti Romania, in order to obtain bone samples type 1A, as recommended by SR EN ISO 527-2:2000. These have a matrix of PBT, the commercial name being Crastin 6130 NC010 (as supplied by DuPont). After the samples' molding, they were heat treated, being maintained for 2 hours at a constant temperature of 175-180ºC.
Wear behavior of the obtained materials was pointed out with the help of a block-on-ring tester and the ranking was in the favor of PBT + 10% aramid fibers as the wear parameter was the lowest and the friction couple has a very poor sensitivity to the variation of sliding speed (0.25-0.75 m/s).

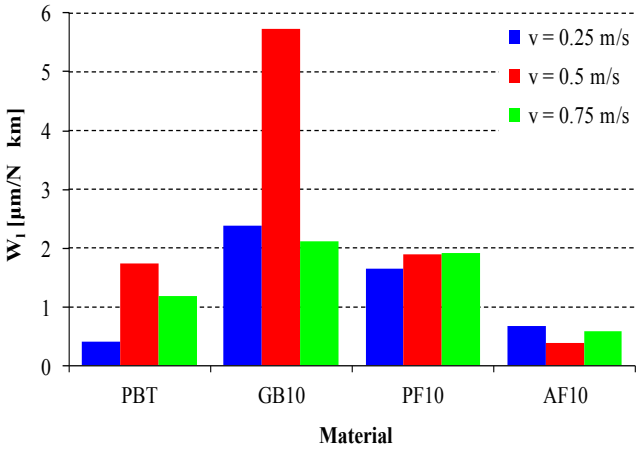


Fig. 2. Linear wear rate of the tested materials for F = 5 N and L = 5000 m

Keywords: polybutylene terephthalate (PBT), aramid fibers, wear, glass beads, PTFE.

Brakes

Chair: Ilmar Santos

Thursday 12 June 2014 – 14.20-15.20

Room: Nortvegia

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Influence of pin contact geometry and friction material behavior on disc brake squeal noise

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Brake squeal noise is defined as a noise at frequencies higher than 1000 Hz and occurring when the system has very high mechanical vibration amplitude, with sound pressure level above 80 dB. Brake squeal remains a very complex phenomenon to investigate because of a wide variety of dynamic aspects at different scales. It is well accepted that squeal noise is associated to mode lock-in of the system modes initiated by the friction forces and leading to self-excitation vibrations. Even if the physical couplings leading to squeal are relatively well understood and identified at the system scale, friction conditions at the interface scale leading to squeal are not well known. This is mainly due to the complexity of the physics between the two surfaces in contact.

In this paper, experimental investigations are performed to study the influence of pad geometry and friction material on squeal occurrences. A simplified set up has been developed : it is based on a pin on disc tribometer with a friction pad attached on a flexible plate fixed on a rigid stand. The pad is made of a specific friction material with only six components. Four contact geometries have been studied with contact length from 10 to 40 mm. In addition, an analytical model of the simplified set-up has been developed. It is a three degrees of freedom including a disc-pad surface contact model with frictional contact surface and friction material behavior.

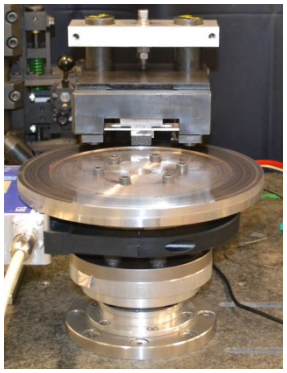

Figure 1 : Experimental set-up

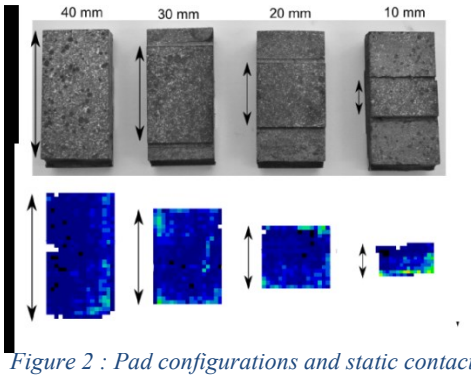

Figure 2 : Pad configurations and static contact localizations

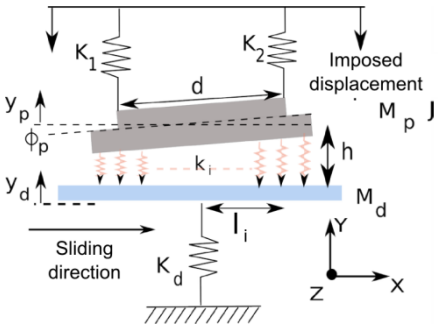

Figure 3 : Analytical model

Results show clearly the influence of the contact conditions on squeal occurrence specially by varying the contact length size. The numerical results are compared to experiments and show the keyrole of the nonlinear behavior of the material. This aspect has been taken into account in the analytical model and results present good agreement with experiments.
This study gives informations on the comprehension of the squeal mechanisms and on the minimal model allowing to simulate the phenomenon.

Keywords: braking, friction, squeal, vibrations, analytical model, nonlinear material behavior

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Influence of snow on train block braking performance – a pin on disc simulation in a climate chamber

Ulf Olofsson[1], Jon Sundh[1], Ulf Bik[2] and Rickard Nilsson[2]

[1] Department of Machine Design KTH Sweden,
[2] Stockholm Public Transport Sweden

The coefficient of friction between two sliding surfaces is a surface and environmental parameter influenced by environmental conditions such as: humidity, temperature and snow. In trains with block brakes the coefficient of friction between the block and the railway wheel determines the braking performance and thus the stopping distance. Traditionally has the blocks been manufactured by cast iron materials. Although, they provide good braking capability during snow and winter condition, their use is more and more restricted due to the squealing noise they produce. Test with alternative block materials has worked well during summer conditions but for regions and countries with snowy winters their use has been limited due to problem with their braking capability during snowy conditions.

This research aims to develop a test methodology in laboratory scale to evaluate the braking capacity of block brake materials. A pin-on disc machine placed in a climate chamber was utilized. In addition to control of temperature and humidity was also snow introduced to the contact. The coefficient of friction and the sound pressure near the contact were measured and the surface topography of the contacting specimens was also measured before and after test. Discs were manufactured from railway wheel material and pins from the block materials. Cast iron block material was in this study compared with blocks manufactured from alternative materials.

The results show that the alternative block materials generate a much smoother counter wheel surface. These smoother surfaces are more easily separated by a water film introduced in to the contact by melting snow resulting in a lower sliding coefficient of friction. In a second test series alternative block materials were evaluated and a candidate material with low noise and high enough sliding coefficient of friction were selected for further studies in full scale.

Keywords: friction, snow, block brakes

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Brass in brake lining: elements of understanding for its replacement

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[2]*Univ Lille Nord de France, F-59000 Lille, France.*
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*(Anne-Lise.Cristol@ec-lille.fr)

In the field of friction braking, the regulation objectives in terms of reduction of the environmental impact (noise, pollutant emission) and augmentation of the energy dissipation performances require the understanding of friction phenomena and of friction material choice, especially for brake lining materials. Since the interdiction of asbestos use, new formulations with organic matrix are developed. Their performances have been significantly improved by formulations ever more complex, including several classes of constituents but without a real understanding of each single function. The development of these friction materials is based on an industrial know-how essentially inspired by feedback and trial-error tests leading to the recipe of formulations but without a structure scientific approach of understanding of the role of each constituent. In this paper, we propose a new methodology based on a simplified formulation derivate from an industrial one and a specific friction test in temperature to identify the contribution of one constituent in the friction behavior of the brake lining material. As copper will be prohibited in few years, we choose to work on brass fibers which contain copper with the aim of providing understanding keys for its replacement. Two materials are manufactured, one without brass and one with 6wt% of brass fibers.

In the first step, the friction materials are characterized. Observation of the microstructure shows that the brass fibers are mainly oriented in the transverse direction. This is due to the fiber shape: they lay down during the hot molding processing. It erases the initial anisotropy of the material and creates anisotropy in terms of thermal expansion. The presence of brass also increases the thermal properties of the material leading to higher temperature reached in the bulk.

In the second step, the two materials are submitted to friction tests at 3 various ranges of temperature: 100-150°C, 200-250°C and 300-350°C. Results in terms of wear show an increase of wear with the presence of brass which can be correlated to higher temperature reached in the bulk leading to higher degradation. In terms of friction coefficient, material with brass shows good performances at medium and high temperatures.

At least, surface observations after friction tests permit to identify the role of brass at the interface. The high thermal properties leads to a high degradation of the material and a high debit flow of 3^d body which is identify by a low presence of secondary plateaus. But brass fibers create also primary plateaus helping to bear the load and to promote the expansion of the secondary plateaus with a very homogeneous in composition. This permits to maintain a good friction level at high temperatures.

Keywords: brake lining, brass, thermal and mechanical characterization, friction tests, 3^d body behaviour.

Test Methods 3

Chair: Markus Varga

Thursday 12 June 2014 – 15.40-16.20

Room: Suecia

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Improvements to Tribological Testing for industry, Practical solutions

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Today's industrial challenges in the ever faster global world include the need to respond and develop ever faster. This means, that tribological issues need to be solved faster and faster. This puts some challenges to the tribology testing community : faster, more efficient testing with correlation to the real applications is needed. On the other hand, the main industrial tribological issue is still wear resistance, and to test wear in realistic conditions usually results in long term testing.
The contradictory requirements of realistic wear testing and fast/efficient testing need to be met, and require some different approaches to the tribological lab testing. These approaches are presented in this paper.
On the one hand, the number of tests can be reduced if precision is improved; precision in friction measurements by a new generation of test equipment, and precision in wear measurements by incorporation of a TLA (thin layer activation) technique on the lab scale. On the other hand, by an approach of parallel testing, the number of test results can be multiplied; this allows comparison of materials and statistical data development while at the same time keeping the cost and time requirement realistic.

Keywords: wear testing, high precision, repeatability, multistation, TLA

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Scratch & Failure Detection Method for Shaft and Rod Surfaces

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The sealing element, the shaft surface, the lubricant and the surrounding comprise the tribological system "seal". The dynamic sealing mechanism (e.g. for a radial lip seal) is based on the reverse pumping capability of the lip seal. This in turn strongly depends on the quality of the shaft counter surface. Surface structures that create superimposed pumping disturb the sealing mechanism and cause failure via either leakage or dryrun. These oriented structures are also known as lead. One method for measuring shafts and analysing microlead has recently been developed and proofed at the University of Stuttgart [0].

Another influence on the surface of shafts and rods are manufacturing and handling failures like scratches and dents [1]. Those do not only pump fluid in an axial direction and cause failure via either leakage or dryrun but also can wear the soft elastomer because of their raised sharp walls. Additionally this effect changes the friction and the complete tribology of the machine element "seal".

A comprehensive quality control is not possible on the present state of technology and therefore not satisfying. For this reason, new approaches are being pursued at the University of Stuttgart to solve these problems. A measurement strategy, based on optical metrology (Fig. 1) and proofed methods of digital image processing provides promising results. With the microlead analysis method like in [0] the orientation of each single grinding structure is analysed and displayed (Fig. 2). In this revision the failures like scratches and dents can be found visually in the disturbed structures of the grinding surface.

Figure 1: *WLI-Surface Topography of a grinded surface with deep scratches due to handling failures*

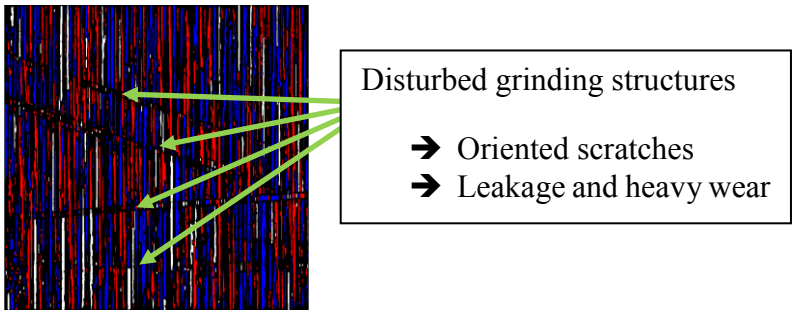

Figure 2: *Microlead analysis software revision V1: Lead orientation of the single grinding structures (red: <-0,1°; white: -0,1°... +0,1°; blue > +0,1°)*

In the actual work the method will be upgraded to separate and analyse the scratches and dents in detail. Information like depth, length, volume and the angular orientation can be calculated and compared to the structures of the original surface. Therefore the failures can not only be found automated but also characterised and compared.

Combining IMA's new analysis methods with a white light interferometer with a rotational unit provides the accuracy, speed and large field of view necessary to properly characterize the shafts at different circumferential positions. This will provide a rapid, reliable production-worthy method to evaluate the quality of shaft counter surfaces and determine if leakage and heavy wear is likely.

Keywords: Surface Topography, Failure Analysis, Scratches, Shaft & Rod, Seal

1. Baumann, M.; Bauer, F.; Haas, W.: Comprehensive Lead Analysis of Shaft Counterfaces for the Tribological System Radial Lip Seal, 22nd International Conference on Fluid Sealing, BHR Group, Düsseldorf, 3./4. Dezember 2013 ISBN: 978 1 85598 139 3
2. ISO 8785 (1998): Geometrical Product Specifications (GPS) – Surface Imperfections

3.

Polymer 3

Chair: Jacob Sukumaran

Thursday 12 June 2014 – 15.40-16.20

Room: Dania

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On the existence of a friction-modified surface layer of BR/SSBR elastomers reinforced with different silica or carbon black contents

***Milad Mokhtari*[1*], *Dirk J. Schipper*[1] *and Tetyana V. Tolpekina*[2]**

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Pin on disk friction tests are performed on different rubber samples in contact with a granite sphere. The rubber samples are prepared from a combination of butadiene rubber (BR) and solution styrene-butadiene rubber (S-SBR) reinforced with different amounts of carbon black or silica. The friction tests are performed at different velocities and loads. Mechanical changes inside and outside the wear track are determined by Atomic force microscopy (AFM) nano-indentation. AFM is used to determine the nanoscale mechanical properties which are compared with the macroscale mechanical properties measured by Dynamical Mechanical Analysis (DMA). The existence of a friction-modified layer as a function of the operational conditions and its effect on friction and friction modeling of a rubber in contact with a rough surface as a function of reinforcement filler and its content is discussed.

Keywords: friction-modified surface layer, BR/S-SBR, AFM nanoindentation, mechanical properties, rubber friction.

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The role of frictional work in tribological behavior of polyamide 66 composites containing hard particles

***Kei Shibata*[1], *Takeshi Yamaguchi*[1], *Moeko Kishi*[1] *and Kazuo Hokkirigawa*[1]**

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Particulate fillers are used to improve the mechanical and tribological properties of resin materials. In previous study, polyamide 66/rice bran ceramics particles (PA66/RBC) and PA66/glass bead (PA66/GB) composites were developed as tribomaterials [1]. However, the role of frictional work in the tribological behavior of these composites has not been reported.

Friction tests were conducted using a rotation-motion-type friction apparatus under dry conditions. PA66/RBC, PA66/GB composites, and pure PA66 were used as pin specimens (Fig. 1). Austenate stainless steel was used as a disk specimen. The sliding velocity was 0.2–2.0 m/s, and the normal load was 9.8–19.6 N.

The friction coefficients for pure PA66 increased with incresing *Pv* value (Fig. 2). Conversely, PA66/RBC composites showed approximately same friciton coefficients, and PA66/GB composites showed a decrease in friction.

The suraface temperatures of pin specimen increased with increasing frictional work, irrespective of pin material (Fig. 3). The maximum temperature was approximately 90 °C, which exceeded the glass transition temperature of PA66 resin.

The specific wear rates of pure PA66 decreased with increasing frictional work, but those were high, particularly at low frictional work (Fig. 4). At high frictional work, softening of PA66 resin occurred because of frictional heat. Then the counterpart material was easily covered with softened PA66. In contrast, except PA66/RBC_26vol% composite, the PA66 composites showed low specific wear rate values, irrespective of frictional work. Unavoidable softening can occur on the composites at high frictional work. However, plastic flows of PA66 were still prevented because of an anchor effect of particulate fillers.

[1] K. Shibata, et al., Final Papers of NordTrib, (2012), 1–6.

Keywords: resin composite, particulate filler, frictional work, sliding wear.

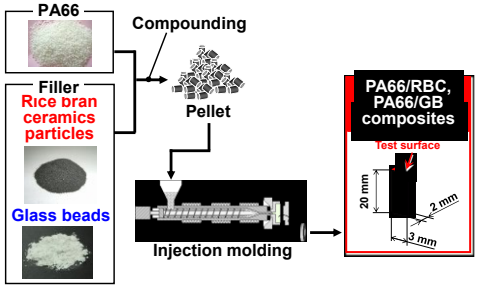

Fig. 1 Manufacturing process of PA66/RBC and PA66/GB composites

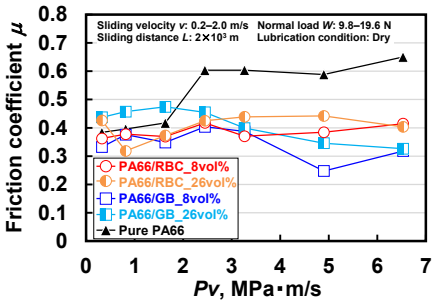

Fig.2 Friction coefficients vs. *Pv*

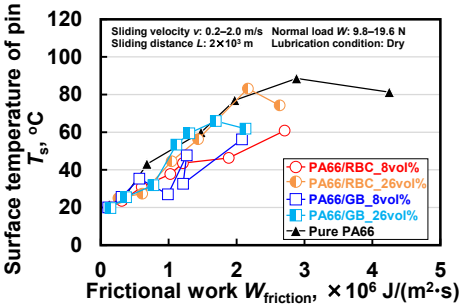

Fig.3 Surface temperature vs. frictional work

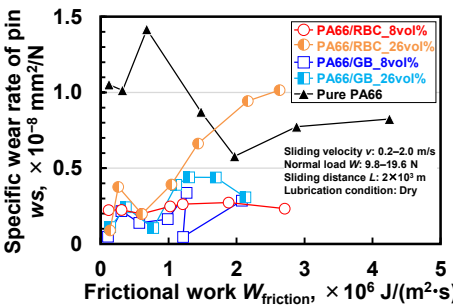

Fig.4 Specific wear rates vs. frictional work

Lubrication 3

Chair: Thomas Norrby

Thursday 12 June 2014 – 15.40-16.20

Room: Nortvegia

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Grease free surface flow on a rotating plate

***J. X. LI*[1], *Lars G. Westerberg*[2], *E. Höglund* [1], *T. S. Lundström*[2],**

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Presenting author: Jinxia Li

In order to improve the understanding of grease flow in various applications such as gears, seals and rolling element bearings, free surface flow of different greases under different running conditions has been investigated. A rotating disc has been used to study grease flow as the grease is subjected to a centrifugal force. The adhesion and mass loss was detected for greases with different rheology on different surfaces and surface textures. It is shown that the speed at which grease starts to move is mostly determined by grease type, yield stress and bleeding properties rather than surface material. Also, the surface adhesion is shown to be influenced both by the rheology of the grease and the surface material.

Keywords: grease flow; axial seal; rheology

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Grease + Water = fatal attraction?

Johan Leckner

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In the real world, it is often difficult, if not impossible, to avoid the ingress of water into bearings and other types of machine elements. The ability of a lubricating grease to withstand, reject or absorb water can therefore be vital to optimal performance in many areas. Using generally available laboratory standards, lubricating greases with different thickener systems have been tested to compare their ability to perform even when contaminated with water. The results are then matched with experiences from real life applications and conclusions drawn on how to select greases for use under wet conditions.

With this study we don't aim at resolving the issue of how bad, or good for that matter, water contamination is in general. What we hope to achieve is to give a balanced picture of how five different greases with a track record from real applications, perform in laboratory tests when contaminated with water. By combining field test data with laboratory data we then hope to be able to give some general advice concerning which greases that are preferred when there is risk of water ingress. A secondary topic that we also will get into is how water is taken up by greases and which components facilitate the incorporation of water into the grease matrix.

Keywords: lubrication, lubricating grease, water contamination, water ingress, laboratory tests, field data

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Novel energy efficient biodegradable turbine oils

[1]Prof. Thomas Norrby, [2]Åke Byheden, [3]Prof. Sergei Glavatskih

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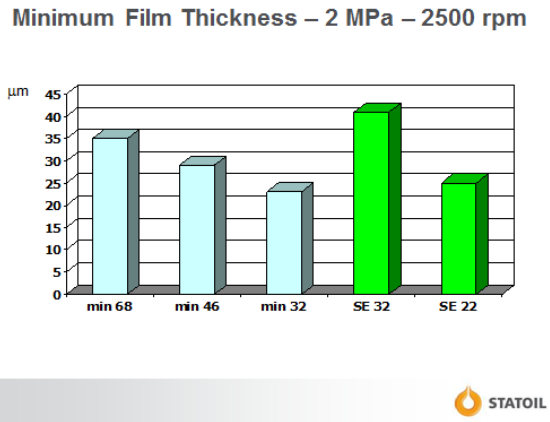
We have called our concept for environmentally adapted lubricants "Environmentally Considerate Choice" (ECC). This concept comprises a broader scope, including not only Bio-lubricants, but also energy efficient/ energy saving products and bio-compatible products with reduced impact on human health in the use phase.

One important area of development has been turbine fluids with high energy efficiency. We have shown that bio lubricant turbine fluids based on advanced synthetic esters (SE) give extra benefits in improved energy efficiency of the turbine systems, in addition to the traditional ones e.g. biodegradability and the use of renewable raw materials.



Another benefit of using synthetic esters is that the well-known problem with sludge and varnish formation is alleviated or prevented. Varnish is formed due to hot spots or static electricity in the system and at the same time poor conductivity and poor solvency properties of the turbine fluid itself. The varnish sticks to the surface of the bearing or inside of the fluid tank and on other surfaces like hydraulic valves. This interferes with the operation, and lead to costly down-time of power generating equipment.

This is an increasing problem, as the Group II and Group III based turbine fluids, designed for prolonged oxidative lifetime (and thus intended longer service life times), are becoming more widely used.

Finding the right combination of antioxidants also helps preserve the fluid, and at the same time minimise sludge formation. This is related to, but not identical to, varnish formation and may cause filter blockage and is in itself an undesirable ageing of the fluid.

In a field trial at a commercial power plant in Nyköping, Sweden, we have demonstrated that a novel ester based turbine fluid yields 20% lower oil and bearing system power losses, which amounts to savings of 0,6% *overall*, corresponding to € 75 000, in an ABB Stahl VAX 35 MW turbine.

Keywords: Turbine fluids, Bio Lubricants, Varnish, Sludge, Energy Efficiency, power loss

PLENARY SESSION 4

Friday 13 June 2014 – 08.40-09.20

Professor Martin Müser

Chair: Ion Marius Sivebæk

Friction mechanisms at small and large scales: New insights from computer simulations

Martin Müser

Forschungszentrum Jülich, Germany

Abstract:
Surfaces of solids tend to be rather complex. They have roughness on a multitude of length scales, the chemical composition is undefined and may even change with time. Yet, the laws describing the friction between two solids are surprisingly simple: To a good approximation, friction between solids is linear in the force squeezing the solids together and independent of the apparent contact area. Moreover, kinetic friction barely depends on the sliding velocity, at least at small velocities.

Many propositions have been made within the last 100 years for the microscopic origin of solid friction and the laws describing it. In recent years, computer simulations have been very successful in testing the competing theories. Some simulations lead to new theories. I will review some of these developments. This includes examples where simulations have triggered new developments for practical applications.

Keywords: Kinetic friction, computer simulations, relations to practical applications.

Biography:
Diploma in Physics from Saarland University in 1992 and PhD in Theoretical Physics from Johannes Gutenberg University Mainz in 1995. He spent his postdoctoral time in the Department of Chemistry at Columbia University and in the Physics & Astronomy Department at The Johns Hopkins University. In 2002, he became professor of Applied Mathematics at Western University in London, Ontario. After a Sabbatical year at IBM, T.J. Watson, New York, he moved to Saarland University in 2009, where he holds the chair of Material Simulations in the Department of Materials Science and Technology. Since 2011, he also heads the Computational Materials Research Group at the supercomputing Centre of Forschungszentrum Jülich. Prof. Müser's research interests focus on the simulation of materials, in particular in non-equilibrium. His best-known contributions elucidate the atomistic origin of friction and the contact mechanics between solids with rough surfaces. A large fraction of his work is concerned with model and algorithm development, such as the design of the first polarizable force field for the description of redox reactions. In 2003, he received the Young Innovator Award from Petro Canada and in 2004 the Premier's Research Excellence Award by the Ministry of Economic Development and Trade, Ontario. He was named Faculty Scholar by Western University in 2008 and Outstanding Referee by the American Physical Society in 2013.

Industrial Tribology 2

Chair: Arto Lehtovaara

Friday 13 June 2014 – 09.40-11.20

Room: Suecia

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Influence of switching speed of connectors in conditions of engaging and separating with electrical load

Alexander Hornung*[1], *Frank Berger*[1], [2]*George Freudiger*, [2]*Tom Ledermann

[1]*Electrical Apparatus and Switchgear Group, Technische Universität Ilmenau, Ilmenau, Germany*
[2]*Research & Development, Multi-Contact AG, Allschwil, Switzerland*
Corresponding and presenting Author: Alexander Hornung, alexander.hornung@tu-ilmenau.de

Plug-in connectors (pins and sockets) are devices used to establish a mechanical and electrical connection between electrical circuits. Often, these connectors are used under extreme conditions (hot plugging), far beyond the manufacturer's qualified conditions. In some cases a failure of the connection is the result. The aim of this research is to gain knowledge about the long-term behaviour of connectors under standardized test conditions and to research threshold ranges in hot-plugged applications. A central point of interest is the influence of mechanical, electrical and other parameters on their operational capability.
In previous times research has been either performed on tribological issues without putting an eye on the breaking capacity or just on the effects occurring when switching under load. However both – tribology and electrical - aspects need to be considered in a combined way at applications of engaging and separating with electrical load when high cycle values has to be reached.
The authors stressed the connectors in numerous tests where they have been switched under different current loads at low direct voltage. During break operation arcing could be observed as expected with both a high speed camera as well as in measured voltages and currents.
The experimental setup also allows a variation of the switching speed according to standard and real-application values. Experiments showed significant differences in connector resistances which depend strongly on the velocity – a slower speed leads to an increased arc energy compared to higher ones. This results in a significant reduction of product lifetime as the connector resistance reaches the crucial limits after fewer cycle times. This paper presents selected experiments and explains the effects of different arc energies on the contact surface.

Keywords: hot-plugging, tribology, arcing, electrical contacts

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Formation and degradation of protective tribofilms on diesel engine valve surfaces

***Robin Elo*, Staffan Jacobson**

The Ångström Tribomaterials group, Department of Engineering Sciences, Uppsala University, Sweden.

The valve system has a critical role in diesel engines. The intake valves open to let air flow in to the combustion chamber, the combustion takes place and then the exhaust valves open to let the combustion products flow out. This is repeated as the engine drives the vehicle forward. At all other times, the valves must be closed to avoid any leakage, which would reduce the power output.

The tribological conditions for the valves are tough and include high temperature, repeated impact and micro sliding in a combustion residue atmosphere. The specified life time of the valves is very long—they should function during the entire life time of the engines—which demands an extremely low wear rate. On top of this, legislation on low emissions of particulate matter and other exhausts is in place. This results in high demands on clean fuels and engine lubricants, which will change the operation conditions for the valves.

We have recently shown that with current technology, protective tribofilms are formed on the sealing surfaces of the valves, which lower the wear rate and thus gives the valves the specified long life time. However, little is known about the mechanisms of how these tribofilms are formed and how they reduce the wear rate. When analyzing field worn valves, it appears as if additive elements from the oil have been trapped between the valve and valve seat insert surfaces as they close. Then—due to micro sliding in the interface—the trapped particles are smeared out into a smooth layer, protecting the metal surfaces. Since a change to cleaner fuels and engine lubricants would lead to less of these tribofilm forming particles it is important to understand this formation process and whether the tribofilm can function without continuous addition of new tribofilm forming elements.

In the present work, the formation and degradation phases of these tribofilms have been studied by running real valves and valve seat inserts in an in-house rig. The rig allows the addition of oil into a hot air stream, which passes the operating valve to simulate the case in real engines. This rig has been used in earlier studies where it has been shown that it can reproduce the type of oil residue tribofilm that is commonly found on field worn valves. The rig allows stopping a test at any point, taking the valve and valve seat insert out to analyze the surfaces and then re-starting the test. To study the build-up phase of the tribofilm, tests have been run for 10; 100; 1000 and 10000 cycles with the addition of engine oil. Also, tests have been continued after 1000 and 10000 cycles for another 1000 cycles—without the addition of engine oil—to investigate if the tribofilm can continue to protect the valves.

The results will be discussed regarding their implications for the development of future valve systems, which will see less and less tribofilm forming elements due to harder legislation on exhaust limits.

Keywords: combustion valve; tribofilm formation and degradation; experimental

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Comprehensive study of wear phenomena during hot rolling of steel

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Wear plates are used for metal sheet alignment prior to coiling during steelmaking. Due to the extreme operating conditions found after hot rolling, like high temperatures, high metal sheet sliding speeds and the use of cooling water, alignment plates suffer severe wear and need frequent repair, thus being a source of increased maintenance efforts and facility downtime.

As a first step towards process optimisation, a damage analysis of wear plates after operation was carried out, using optical microscopy, micro-hardness measurements and SEM imaging in order to investigate their microstructure and wear mechanisms. In addition, comprehensive analysis of the highly stressed near-surface region was done using SEM+FIB and electron back scattering diffraction (EBSD) mapping for investigation of early damaging phenomena.

In particular, two main damage mechanisms were identified: the initial onset of the wear tracks was attributed to (i) 2-body abrasion by the high temperature sheet metal, while at a later stage (ii) significant plastic deformation of the substrate and mixing with transferred material from the counterbody as well as oxides was found (Fig. 1), eventually leading to plate material loss due to the delamination of the mixed layer. Microstructural changes were observed in the plates' base material, including the formation of a hard surface layer possibly due to the joint thermal and mechanical effects of the contact with the high temperature metal sheet. It is expected that the microstructural evolution of the base material will influence the tribological behaviour of the wear plates.

Experimental simulation of the predominant wear phenomena observed during the failure analysis was carried out on a two-body abrasion test rig in lab-scale. Testing parameters were best-adapted to real field conditions (e.g. temperature, sliding speed, contact load). Wear evolution was observed from the very beginning to advanced stages of the process. Results showed that the predominant wear mechanisms change with increasing testing time from sliding contact phenomena to intermixing and adhesion at later stages.

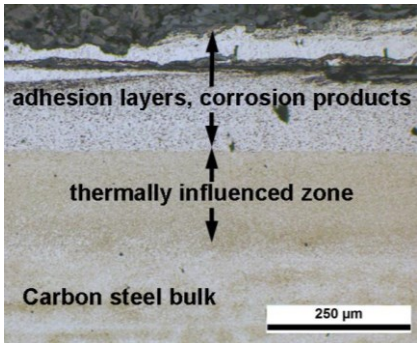

Fig. 1: Cross section of a damaged region at an advanced stage of the wear process

Keywords: High Temperature, Sliding, Abrasion, Tribology

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Friction behaviour of phosphate-free lubricants for steel wire drawing

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In cold forming processes, finished parts are produced from semi-finished products where lubricants are applied to reduce direct contact between tool and workpiece. The large surface expansion and high normal pressure combined with elevated contact temperature between workpiece and tool, which prevail in cold forming of metals, cause the necessity of high performance lubrication systems. Nowadays, phosphate coatings as conversion layers represent the industrial standard. However, phosphatising produces hazardous wastes and is a major bottleneck directly affecting productivity. In this way, alternative lubrication systems are continuously demanded.

In the present work, several alternative phosphate free lubricant systems are applied on wires in industrial drawing conditions. The coefficient of friction of as-applied lubricants is characterized by means of a modified scratch test. Measurements are made directly on lubricated wires, representative of industrial conditions. Additionally, multi-pass effect has also been studied to determine lubricant run dry stability, surface enlargement and roughness flattening.

Keywords: lubrication, friction, steel wire, drawing

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Development of new tapping tool covered with nickel/abrasive particles composite film

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Recently several types of tapping tools covered with hard coating film have developed in order to elongate its tool service life. However, detachment of the film from the tool surface or chip snarling on the tool is problem for further increase of tool service life and tapping speed. In this study, a tapping tool covered with nickel/abrasive particles composite film was newly developed and its superior machining performances were investigated.

Fig. 1 shows an overview and SEM images of newly developed spiral tap covered with nickel/cubic boron nitride (cBN) particles composite (Ni/cBN) film. The composite film was formed on the tool surface by electrodeposition method. The mean diameter of cBN particles was about 10 μm.

Tapping tests were carried out with a machining center using high-speed tool steel (HSS) tap with homotreatment, and HSS tap covered with TiCN, Ni, or Ni/cBN film. The workpiece material was carbon steel (JIS S45C). The cutting velocity was 10 or 50 m/min. The number of 25 holes was processed.

As shown in Fig. 2, as compared to the HSS tap covered with TiCN film, there found no chip snarling on the newly developed tap covered with Ni/cBN film at cutting velocity of 50 m/min. The tap covered with Ni/cBN film was able to prevent chip snarling even at high cutting velocity condition whereas the other taps had chip snarling (Table 1). This result indicated that the newly developed tap enables continuous tapping process at high cutting velocity (50 m/min) than the conventional condition. On the basis of the observation and analysis of chips after test, the tap with Ni/cBN film reduces the length and the curl radius of the chip possibly due to abrading action of cBN particles on chip surface.

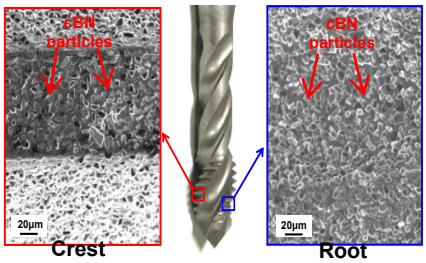
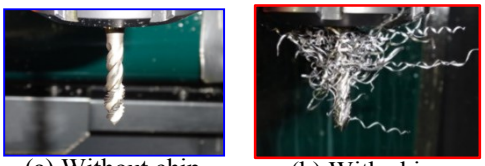


Fig. 1 SEM images of spiral tap covered with Ni/cBN film



(a) Without chip (tap covered with Ni/cBN film)
(b) With chip (tap covered with TiCN film)

Fig. 2 Snap shot of tapping tool after

Covered film on tapping tool	V_r = 10 m/min	V_r = 50 m/min
Homotreatment	No chip snarling	Chip snarling
Ni plating	No chip snarling	Chip snarling
TiCN film	Chip snarling	Chip snarling
Ni/cBN particles Composite film	No chip snarling	No chip snarling

Table1 Occurrence of chip snarling

Keywords: chip snarling, cubic boron nitride, electrodeposition, friction, tap

Bearings

Chair: Martin Müser

Friday 13 June 2014 – 09.40-11.20

Room: Dania

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Crack propagation in silicon nitride bearing elements

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Catastrophic fracture failure of engineering structures is caused by cracks that extend beyond a safe size. Cracks, either as a result of manufacturing fabrication defects or damaged in service, may grow by mechanisms as fatigue, stress corrosion or creep. The crack growth leads to a decrease in the structural strength. Fracture, the catastrophic damage that takes place very rapidly, is preceded by slow crack growth during normal service conditions, mainly by fatigue due to cyclic loading.

Silicon nitride is one of the most important materials for rolling element bearings applications. However, the difficulties of sintering and machining the material may result in surface defects. Surface defects as ring cracks are difficult to detect during high volume production process. Another surface cracks caused by blunt impact load have also ring shape and are the most common type found on ceramic ball surface. These defects decrease the rolling contact fatigue performance considerably so it is important to understand the failure mechanisms caused by such cracks.

The stress intensity factors along crack front were analyzed using a three-dimensional boundary element model. The boundary element method (BEM) is a numerical computational method of solving linear partial differential equations which have been formulated as integral equations. It can be applied in many areas of engineering and science including fluid mechanics, acoustics, electromagnetic. The dual boundary element method is also used in fracture mechanics in incremental analysis of crack extension problems.

The numerical analysis was verified by experimental studies. A four-ball apparatus was used to test ceramic balls. The upper ball is the silicon nitride test specimen with a pre-existing ring crack. The ring cracks were created by blunt impact loads. This method was chosen to create similar cracks which can be created during falls of the balls or exploitation as an effect of impact load.

Based on the experimental research and numerical analysis the following conclusions may be drawn:

- The process of fatigue failure of silicon nitride with surface ring cracks is influenced not only by the pre-test crack propagation. Generated subsurface cracks play an important role in rolling contact fatigue performance and failure modes.
- The main problem in numerical analysis is comparison of calculated stress intensity factors in rolling contact of silicon nitride with existing information in the literature because of contradictory information.
- The structural quality of materials, working environments and external load magnitudes have a significant impact on the life of rolling elements in bearings.

Keywords: crack propagation, silicon nitride, rolling bearing, numerical analysis

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Application of multilobe journal bearings in grinding machines spindle systems

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Multilobe journal bearings are applied mainly in high speed rotating machinery, e.g. turbo compressors, turbines or in grinding machines. Hydrodynamic journal bearings can properly operate in the strictly determined range of rotational speeds which upper boundary is determined by the permissible temperature of operation and the possibilities of heat conduction, but the lower determines the occurrence of fluid friction. It is convenient to apply such bearings in the grinding machines. However, to operate the grinding machine spindle bearing system at proper temperature it is important to apply the bearings assuring comparatively low temperatures of oil film. Using multilobe journal bearings with 3, 4 or 6 lobes of continuous can fulfill such condition of operation or non-continuous bore profile. The ground for the safe operation of multilobe journal bearings at proper oil film temperature is the knowledge of bearing thermal characteristics particularly the oil film maximum temperature. An excessive oil temperature leads to the degradation of lubricant, bearing material and it generates deformations of bearing structure.
An example of application of multilobe bearings with discontinuous bore profile gives the journal bearing system of grinder for peripheral grinding; this grinding machine spindle operates in 3-lobe bearing with pericycloid (continuous, “wave”) bore profile. Another example of bearing applied in grinding machine is the 4-lobe bearing with discontinuous bore profile.

Classic 3-lobe journal bearing is composed of single circular sections whose centres of curvature are not in the geometric centre of the bearing. The geometric configuration of the bearing as a whole is discontinuous and not circular. The 3-lobe pericycloid journal bearing “wave” bearing) is characterised by continuous profile and three hydrodynamic oil films on the journal perimeter. Continuous curvature of the operating surface is an important feature of the pericycloid bearing. Such a configuration allows simultaneous machining of the whole surface by simple workshop techniques and hence precise shape as well as the dimensional accuracy.

The paper presents the results of the calculations and experimental investigation of oil film pressures and temperatures of multilobe journal bearings that were applied in the real mechanical system of grinding spindle. The oil film pressure, temperature and viscosity fields were obtained by iterative solution of the Reynolds', energy and viscosity equations. Laminar adiabatic and diathermal oil film, static equilibrium position of journal and parallel axis of journal and bearing were assumed. The calculated temperatures were compared to the temperatures obtained experimentally on the test rig designed on the basis of real grinding machine spindle system.

Keywords: hydrodynamic lubrication, multilobe journal bearings,

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Experimental Investigation of Fatigue Lifetime for Bearing Materials in Large Two-stroke Marine Diesel Engines

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In large two-stroke marine diesel engines bearings are designed with the intention that these need not be replaced during the life of the engine. The design parameters of the main bearings are, among others, based on the average maximum specific load which the bearing should operate under. The frictional loss is less than 1% of the nominal power of the engine, but is still a target for optimization. Fatigue mechanisms of bearing lining material are not fully understood and the design limits with regards to minimum oil film thickness, max oil film pressure and oil film pressure gradient is not established. Large two-stroke journal bearings are not suitable for fatigue test due to the size, the low rotational speed and the complexity of such test-rig. The Disc Fatigue Test Rig (DFTR) was designed with the purpose to test white metal coatings under realistic bearing conditions, in a confined time-frame. The test-rig simulates a scale model of a thrust bearing, in contrary to standard design the bearing lining material is applied to the rotating collar. On each side of the disc three stationary tilting-pads applies a load to the test disc, with a rotational speed of 2000 rpm. Parameters, such as bearing load, rotational speed, oil temperature, oil contamination is controlled/monitored in order to ensure a systematic approach to the experiments and to achieve a high degree of repeatability. Test performed on the test-rig shows good correlation on the fatigue cracks with those experienced on large two-stroke journal bearings. Observations from the experiments are shown alongside with results from service experiences. Measured parameters are used for monitoring the condition of the white metal lining during the experiment.

Keywords: Babbitt, fatigue, combustion engine, experiment

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Pressurized oil supply in cylindrical 2-grooves journal bearing

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The main shafts of hoisting machines applied in coalmines can operate in rolling or journal bearings. Journal bearings are characterized by very low friction coefficient, very good reliability and durability. They allow easy assembling as well as smooth operation without vibrations. Lubricating system of journal bearings is very simple and it provides continuous pressurized oil supply to the bearing operating surfaces. In case of hoisting machines the low speed of operation does not generate high oil film temperatures. Design of such journal bearings should base on good knowledge of their performance characteristics. Main design elements of hoisting machine including main shaft, journal bearings and electric motors are designed to assure the reliable operation through 50 years exploitation.
Determination of bearing characteristics requires the knowledge of load applied to the bearing. This load can be obtained from the solution of the equations of motion of hoisting machine.
Static characteristics of journal bearings include: oil film pressure, temperature and viscosity distributions, load capacity that is usually determined by Sommerfeld number, static equilibrium position angle, minimum oil film thickness, maximum value of oil film pressure and temperature, friction loss and oil flow. Basic equations of hydrodynamic theory of lubrication, i.e., Reynolds’s, energy and viscosity equations including geometry of oil gap are the ground of bearing static characteristics. The supplied oil pressure and temperature affects the operation of journal bearings. These parameters of lubrication are of great deal in case of very responsible journal bearings systems such as the bearings of hoisting machine.
An example of hoisting machine operating with 2-axial groove cylindrical journal bearings is the machine allowing the transportation of coal from the depth, about 700 meters. This hoisting machine operates with very stiff shaft with fixed winding drum rotating at 70 rpm. The shaft is designed to connect two direct current electric motors of 3400 kW power each and it runs in two in two large overall dimensions of 650 mm nominal diameter journal bearings. Lubricating grooves are placed in the horizontal plane of bearing. Such design classifies these bearings as two-axial groove cylindrical journal bearings.
This paper presents the effect of pressurized oil supply on the static characteristics of low speed, heavily loaded, large overall dimensions two-axial groove cylindrical journal bearings of hoisting machine. Different pressures and temperatures of supplied oil were assumed. Reynolds, energy and viscosity equations were solved by the method of finite differences. Diathermal model of oil film, laminar oil flow in the bearing lubricating gap and parallel orientation of bearing and shaft axis were assumed. All calculations were carried-out at the static equilibrium position of journal. Some of the results of calculations were compared to the values of temperatures measured by hoisting machine monitoring system.
Keywords: cylindrical 2-grooves journal bearings, pressurized oil supply

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Solution for deposition on bearing pads by insoluble particulates in turbine oils

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Even slight oxidation degradation could significantly impair device functionality. In recent years, deposits have been recognized as problem reaching epidemic proportions in some applications (1) (2) (3). This is thought to be related to the change in base oil from Group Ⅰ to Groups Ⅱ or Ⅲ.

So far, we have confirmed that particulate insoluble products increase, even with unchanged viscosity and total acid number; depending on the base oil type Groups. Moreover, it was also confirmed that very few insoluble products were responsible for deposition though the demonstration tests that was simulated the thin gap in the film thickness as shown in Fig2.

The potential solution for this problem is to choose good oils and remove contaminants. In this paper, the dependence of oil type on deposit formation and the filtration effect using Electrostatic Oil Cleaners (EOC), which makes use of principles that the contaminants in oil are electrically charged and trapped by electrodes, are reported. The test results are illustrated in Fig3. Even small particles below 10μm can be removed.

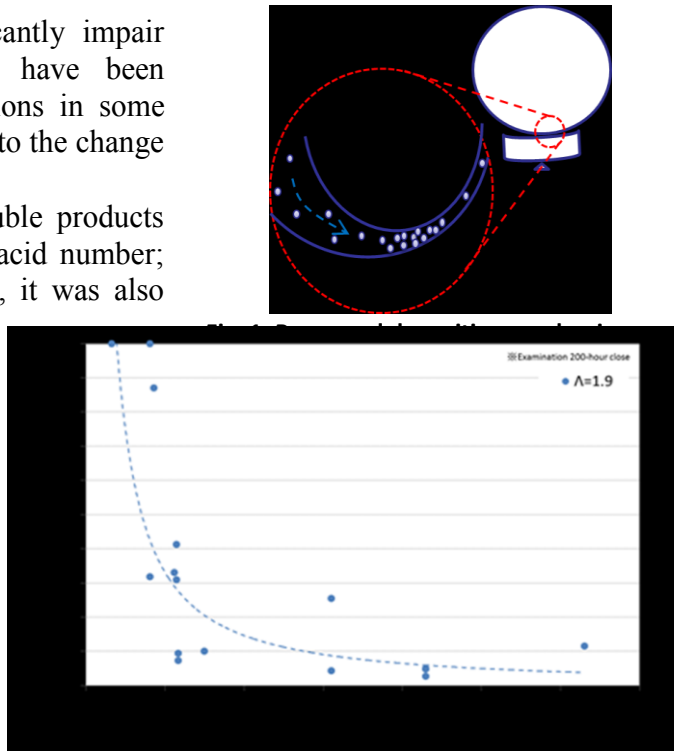

Fig. 2. Demonstration tests as a function of contamination content

List of References

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[2] M. J. Neale: Tribology Int., August (1982) pp. 184-186
[3] G. J. Livingstone, et al.: J. ASTM Int., Vol. 4, No. 1, paper ID JAI100465

Keywords: Deposit, Lubricant, Turbine oil, Bearing

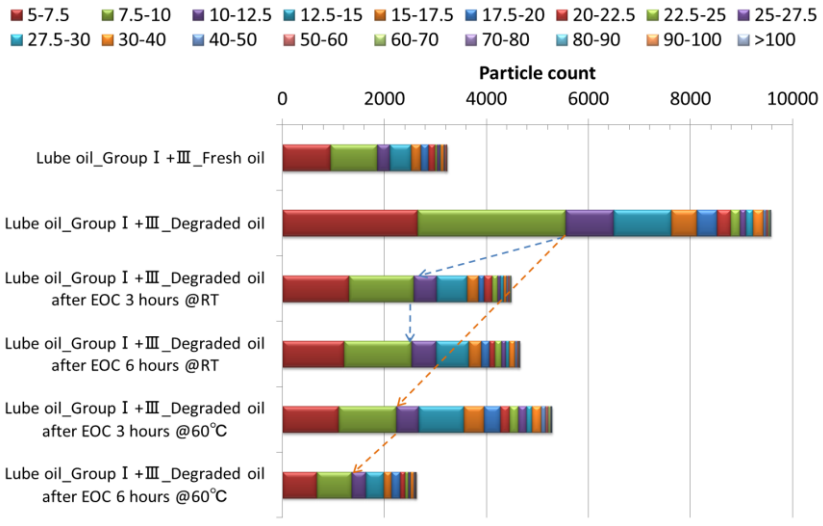

Fig. 3. the filtration effect using Electrostatic Oil Cleaners (EOC)

Tribology of Materials

Chair: Staffan Jacobson

Friday 13 June 2014 – 09.40-11.20

Room: Nortvegia

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Friction and wear characteristics of different Pb-free bearing materials in mixed and boundary lubrication regimes

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Traditional bearing materials contain different amounts of lead (Pb) due to its friction reducing properties. However, in view of the negative health and environmental impact of Pb, there are new directives that limit the usage of Pb in engine bearings. Owing to this, new bearing materials that provide at least comparable tribological performance to that of Pb containing alloys are emerging and manufacturers have already started manufacturing Pb-free bearing materials. It is, however; still unclear how these new engine bearing materials would perform in mixed and boundary lubricated conditions. In this study, a block-on-ring test setup was employed to investigate the tribological performance of several bimetal and multi-layer Pb-free bearings with different compositions of lining and overlay materials. Pb-containing bearing material was also studied as a reference material. Friction and wear properties of these bearing materials were investigated and their wear mechanisms under lubricated conditions have been analysed.

Keywords: lead-free; bearing materials; friction and wear

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The effect of sliding distance and temperature on the initiation and formation of the aluminium alloy transfer to the uncoated and coated tool steel

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In processes of forming aluminium alloys, there are several difficulties in controlling process parameters and product quality due to the unfavourable contact conditions and tribological properties of the contact surfaces. Because of the lower required forming forces and higher material formability, most of the aluminium bulk-metal forming (i.e. forging, extrusion) is performed at elevated temperatures, which causes substantial thermal and mechanical stresses and die surface wear due to the abrasion and adhesion. Adhesion and in particular formation of the aluminium alloys transfer on the surface of die bearing surface is one of the predominant reasons for tool failure and inadequate surface quality of products.

The present work was focused on the aluminium alloy (EN AW6060) transfer initiation and evolution onto the coated (CrN and TiAlN) and uncoated nitrided hot work tool steel (AISI H13) in a temperature range from 20 °C to 500 °C. All tests were performed on the new Load scanner tribo test rig in a dry sliding contact conditions. The contact has been investigated in terms of the surface area and volume of the transferred aluminium alloy to the uncoated and coated tool steel surface, the topography of the wear trace and corresponding change in the coefficient of friction.

The results show a strong dependence between temperature and the tribological properties of the uncoated as well as coated tool steel and aluminium alloy sliding contact. In contrast, sliding distance shows only a limited impact on contact behaviour, especially at higher tested temperatures.

Keywords: elevated temperatures, friction, galling, aluminium alloy, coatings

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A pin on disc study of the tribology characteristics of sintered versus standard gear materials

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Presenting author: Xinmin Li

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Powder metallurgy allows complex component geometries which includes gears. There is however a lack of knowledge of the tribological performance of powder material gears compared to gears manufactured from standard gear materials. In this study, a pin on disc machine was used to simulate the sliding part of gear tooth contact both in boundary and mixed lubricated regions. A comparative study of the tribology characteristics of two kind of sintered gear materials with a standard gear material was performed. The comparison comprised of damage mechanisms, wear, friction and running-in between these materials in different pin on disc configuration (standard vs standard, sintered versus sintered and sintered versus standard). For the same gear materials combinations [RS-RS (16MnCr5), AQ-AQ (Distaloy AQ+0.2%C) and Mo-Mo (Astaloy 85Mo+0.2%C)], RS gear material has a lower friction coefficient. When it comes to PM and RS material combinations, both of the PM materials showed a lower friction coefficient, when the pins are made of PM materials in contrast if we have RS pin. Also for the wear rate, RS material always shows the lowest wear rate no matter the disc material. AQ and Mo gear materials have nearly the same wear rate. A distinct difference between different material combinations, both in friction and in wear rate, is observed during the running-in phase.

Keywords: Gear material, PM, wear, friction, running-in

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Wear of Thermally Sprayed Silicon Carbide Composite Coatings under Lubricated Contacts

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Presenting author: Fahmi Mubarok

The wear characteristic of thermally sprayed silicon carbide composite coatings were assessed under polyalfaolefin lubricated contact with different temperature set-up. The SiC coating produced within this experiment was sprayed with atmospheric plasma spraying techniques. The coating was successfully deposited since the feedstock was modified beforehand to limit the SiC decomposition using co-precipitation method. This method allow 30wt.% yttrium aluminum garnet binders originated form its metal salt precursor to be layered on the SiC particles surfaces. The coating tribological tests have recorded lowest coefficient of friction (COF) of 0.10 and 0.15 when AISI 440C ball and SiC ball was used as the counterpart respectively. The wear track morphology indicates that polishing of asperities and some grain ploughing in the coatings was the major wear mechanism. Nevertheless, in all cases, the wear losses were negligible.

Keywords: atmospheric plasma spraying, silicon carbide, tribology, lubricated contact

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Adhesive strength of coated film by aerosol deposition using reactive alumina submicron powder

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Recent advances in smart surface engineering, coating technologies and cold spray technologies offer unique possibilities for better controlling friction and wear under lubricated rolling, sliding or rotating contact conditions. Smart surface technologies such as laser texturing and/or dimpling, laser glazing, reactive ion etching and shot-peening have also become very popular. Recently, a novel method for depositing ceramic thick films by aerosol deposition (AD) has been developed. Submicron ceramics powders are accelerated by fast gas flow and then impacted on a substrate, to form a dense, uniform and hard ceramic layer at room temperature. In this study, in order to create the textured surface without the thermal effect, AD method was employed. The conditions to deposit alumina films on a slide glass and the adhesive strength of the films were investigated. The thickness of deposited alumina film increased exponentially, as the reciprocating cycles increased in numbers. The deposited films were scratched using a diamond indenter. The friction coefficient of contact between the film and the indenter was almost 0.15 in spite of reciprocating cycles. The reciprocating cycles in depositing exceed 20, the adhesive strength of the films increased from 75N to 90N.

Keywords: aerosol eeposition, alumina, coating, adhesive strength, submicron powder

POSTER SESSION

Wednesday 11 June 2014 – 15.40-17.00

4

Modelling of nonlinear dynamic of mechanic systems with the force tribological interaction

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** Presenting author*

This paper considers the mechanisms with different structure: tribometric device and a mechanism for handling of optical glasses. In the first device, the movement of the upper platform is due to a reciprocating friction interaction. In the second device, the processing of the optical element or group of elements occurs due to the rotational motion. Modeling of the dynamic of these systems with Matlab/Simmechanic allowed carrying out the analysis of dynamic of mechanisms considering nonlinearity tribological interactions for these systems. The article shows that using the computer models can effectively carry out the selection of the control parameters to create the desired mode of operation, as well as to investigate the behavior of systems with nonlinear parameters and processes of self-oscillations. The organization of the managed self-oscillation process is realized to create the relevant high-performance manufacturing, for example, for the processing of optical glasses.

Keywords: handling of optical glasses, tribometric device, friction models, nonlinearity tribological interaction, simulation in Matlab.

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Researches on the Friction between the Guide made of Phosphor Bronze and the Valve Stem made of Ti6Al4V with and without Protective Layer

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Lightweight valves are commonly used in modern combustion engines with cam and camless valve train. They can be made of TiAl alloys and in particular the inlet valves can be made of Ti6Al4V. The stems of such valves can be coated by protective layer obtained by nitridation, chroming or the other one. The stems can mate with guides made of cast iron, of phosphor bronze or berylium bronze. Mating can take place in conditions of mixed friction with different share of lubricated friction. The researches have been provided in the tribotester. The analyzed valve has been driven electromagnetically, for the different valve strokes and frequencies. The guide has been warmed electrically to the desired temperature. The mating takes place in the condition of oil absence. The valve has been loaded by additional mass to induce the normal force between valve stem and its guide. It has been measured the acceleration and the displacement of the valve, the impact force of the valve into its seat insert, friction force between valve stem and its guide, the temperature of the guide and the sound level. The aim of the researches is to obtain and compare values and courses of friction coefficient between the guide made of phosphor bronze and valve stem made of Ti6Al4V for certain number of the valve strokes, frequencies and temperature of the guide. The researched stem can be uncoated or coated by Cr layer or by nitridation. The model of valve and guide has been elaborated using FEM to compute temperature gradient in valve material. Obtained values of the guide temperature has been used as the boundary conditions in the model. The analytical model has been elaborated to calculate the contact pressure and the friction force between valve stem and its guide for the conditions of mixed friction occurring because of selected engine oil and of the valve motion relative to its guide as obtained from the tribotester. The obtained dry friction coefficient values have been used in the model. Results of researches have been presented in the article.

Keywords: friction, tribotester, TiAl alloy, phosphor bronze, protective layer.

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Tribological Analysis of the Nano-modified Industrial Polymer

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The aim of this paper is a research of positive influence of the commercially available nano-additive on tribological properties of the essential polymer for the industry. The nano-filler amount was chosen equal to commonly needed for amending of other paramount properties of the polymer. The tribological behavior of polymer nanocomposite was investigated during the rubbing against low alloyed steel in oilless contact. The composites consist of Ultramid which was modified by 1, 3 and 5 wt.% of nanoclay Cloisite. Samples were tested on T-05 block-on-ring tribometer and observed with SEM and Laser Confocal Microscope LEXT OLS 3000. There were observed a positive and pronounced effect of nano-additive on temperature regulation in contact zone, investigated and analyzed other aspects of tribological behavior of a polymer/steel contact joints.

Keywords: polymer, nanoparticles, wear, Ultramid, Cloisite, dry friction, oilless contact.

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Wear and Mechanical properties of nodular iron modified with copper

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The nodular iron is a material that has shown great advantages respect to other materials (steel and gray iron) in the production of machine elements. The engineering industry, especially automobile, are potential users of this material. As it is known, the alloying elements modify the properties of steels and castings. Copper has been investigated as a structural modifier of nodular iron, but studies of its mechanical and tribological implications still need to be addressed for industrial use. With the aim of improving the mechanical properties of nodular iron, alloying elements (Mn, Si and Cu) are added in order to increase their pearlite (or ferrite) structure according to the percentage of the alloying element.

In this research (using induction furnace process) nodular iron with three different percentages of copper (residual, 0,5% and 1,2%) was obtained. Chemical analysis was performed by optical emission spectrometry and microstructures were characterized by Optical Microscopy (ASTM E3). The study of mechanical behavior was carried out in a mechanical test machine (ASTM E8) and a Pin on disk tribometer (ASTM G99) was used to assess wear resistance. It is observed that copper increases the pearlite structure improving the wear behavior; tension behavior. This improvement is observed in higher proportion with 0,5% due to the fact that too much increase of pearlite leads to ductility loss

Keywords: copper, mechanical properties, nodular iron, pearlite structure, wear.

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Observation of Elastic/Plastic Response of Adsorbed Mono-Layer to Friction by Lateral Force Microscopy

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Boundary film on a solid surface in practical sliding contacts should be an imperfect film, not an idealized film with infinite extent such as LB film. In the case of relatively low coverage of molecular film, the boundary film can be small island shape because of nucleation. In fact, many observations of the island shape molecular film with atomic force microscopy have been reported. This fact suggests that one of the origins of friction force in boundary lubrication should be mechanical response of a mono-molecular island film.

In this study, mechanical response, that is elastic/plastic response to friction, is observed with lateral force microscopy for various types of island shape molecular film; normally aligned or oblique aligned cohesive film of octadecyltrichlorosilane(OCT) in decane liquid, and normally aligned cohesive film of stearic acid(SA) in octadecane liquid and in stearic acid solution with decane as solvent.

In the case of the normally aligned film of OCT, as to film thickness during friction, elastic response is observed up to relatively large normal force. On the other hand, height of oblique aligned film of OCT indicates elastic/plastic response against normal force during friction. In this case, the plastic strain of film height is quantized by lean by gap of all-trans configuration of alky chain of OCT.

The normally aligned film of SA is also deformed elastically in lightly loaded friction or plastically in heavily loaded friction in SA solution although, in decane solvent, it is destroyed during friction from peripheral area of island as dissolution into decane solvent.

Keywords: mono-layer, boundary film lubrication, friction, elastic/plastic response, LFM

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The Resource Estimation of heavy-loaded friction units of internal combustion engine

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The task of boosting energy-efficiency and reliability of diesel engines is associated with the improvement of the design of friction units, because the thermal loads, gas and inertial forces are increasing. The integrated approach in the design of new engines is necessary. It takes into account all important factors affecting the performance of the engine friction units. The most units of friction in the engine are heavily loaded. In this case, the load changes over time in magnitude and direction. Therefore approaches, which based on solving the problems of the dynamics and the hydrodynamic lubrication theory of friction units in the present work, were used. Applied methods take into account the particular geometry of friction units and crankshaft, non-Newtonian properties of the oils, operating parameters.

On the basis of experimental studies and modern methods of calculation the performance criteria of hydrodynamic friction units were used: the minimum permissible lubricant film thickness; the maximum permissible hydrodynamic pressure; the maximum permissible specific bearing load. The minimum permissible lubricant film thickness is selected from the conditions for ensuring the hydrodynamic regime of friction in heavy-loaded friction unit. The minimum lubricant film thickness must be more than the average amount of micro-asperities of interacting friction surfaces.

The main condition for safe operation of friction units is to increase the minimum lubricant film thickness $h_{\min}$ between the surfaces, for which does not take place the contact of micro-asperities. This is achieved by the high precision machining of the friction surfaces, by the strict observance of round form of shaft and bearing (for the case of circular-cylindrical unit of friction), by excluding distortions and deformations, as well as a thorough cleaning oil.

The assessment of performance of bearings is based on calculating the hydro-mechanical characteristics (GMC) of friction units. Furthermore zones, where the minimum lubricant film thickness is less than the minimum permissible lubricant film thickness value h_{pr}, were taken into account. If in some moments of the engine work $h_{\min} < h_{pr}$, this means that in this area abnormality liquid lubrication occurs and bearing operates under mixed lubrication during some part of the work engine cycle.

Along with a minimum lubricant film thickness the maximum value of the hydrodynamic pressure must be taken into account. They determine not only the carrying capacity of the bearing, but and the fatigue life of the inserts of friction units.

The kit of the GMC, which is produced in a parametric studies of heavy-loaded friction units, allows only indirectly assess their durability. The calculation of GMH is based on decision of three interrelated problems: the calculation of the dynamics of mobile elements of tribo-units; the definition forces of the hydrodynamic pressure in lubricating layer; the evaluation of thermal state of friction units.

The task of calculating the dynamics heavy-loaded friction unit reduces to determining the trajectory of the mass center of each of the movable element under the influence of the external periodic load. The trajectory is based on the coordinates that are obtained by solving the equations of motion. The field of hydrodynamic pressures necessary for the calculation of the reaction of the lubricating layer, was determined by integrating the Reynolds or Elrod equations subject to the availability the lubrication sources on the friction surfaces (holes, grooves). Simultaneously, the rheological properties of the

lubricant were involved. To assess the thermal state of friction units the isothermal or non-isothermal approach was used.

The resource estimation of friction units is made on the basis of molecular-mechanical theory of friction and wear fatigue theory (Kragelsky), as well as on the basis of the dynamics equations of wear using the calculated GMH. The possibility of using the developed method was shown by the example of calculating the dynamics of connecting rod bearings of the crankshaft of the engine.

Keywords*:* resource, heavy-loaded friction units, hydro-mechanical characteristics, bearing

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Tribological properties of friction pair Al_2O_3/IF-WS_2 composite layer with the TG15 plastic

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The aim of this study is to present the result of tribological tests and geometric structure of the surface measurements. The top layer of anodized (porous) aluminium-oxide film was loaded with fullerene-like nanoparticles (NP) of WS_2 (IF-WS_2). The impregnated IF nanoparticles are intended to improve the wear resistance and reduce the friction of the top-layer [1, 2]. The tribological properties was investigated by conducting wear tests of Al2O3/IF-WS2 coatings against TG15 plastic counterbody under pin-on-disk reciprocating motion. The friction coefficient was described by the raw data obtained from the experiment. Such data were a set of stochastic signals probed with a constant frequency. The data were smoothed by a moving average procedure [3] being a low-pass digital filter. The smoothed data were modelled by a special kind of a piecewise linear function being a specific parametric model [4]. The straight-line sections were combined by a smoothing kernel what guaranteed differentiability class C^{ω} required by a fitting procedure. The parameters of the model were fitted as maximum likelihood estimates [5] with assumption that the noise is an additive term of the model. The identified *model was the base for further calculations.*

Keyword: oxide layer, composite layer, lubricants,wear, friction coefficient

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Tribological behavior of epoxy and epoxy composites

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Despite their ecological disadvantages the epoxy resins are still used on a large number of industrial and domestic applications firstly because of their versatility and secondly because of their exceptional physical, mechanical and chemical properties. Showing poor electrical properties the epoxies represent a challenge for the researchers and technological users who are seeking for various ways to improve, at least, the electrical conductivity of polymers. The organic electronics had opened a large and extremely promising window toward a trans-disciplinary domain of human knowledge. It is well known that the best way to improve the electrical properties of a media is to fill it with a significant amount of conductive elements. CNTs, fullerenes, graphenes, carbon black, ferrites, various ionic compounds had been used as fillers in order to change the electrical behavior of thermosetting polymers. Following this, path notable results had been achieved but always they are associated with poor mechanical properties of materials due to the presence of fillers' particles. In other studies the influence of starch over the properties of epoxy resin had been investigated and it was shown that an amount of starch of 10% volume ratio is not changes the basic properties of the epoxy matrix excepting the transparency of the material and its chemical tenacity under the action of high active solvents and acids. On another hand the starch is suitable to obtain chemical complex substances which might place free radicals in epoxy's volume. This study is developed to analyze the effect of ultra-sonication over the properties of epoxy resin and over the properties of starch filled epoxy compounds. The emphasis is on the tribological behavior of materials during the pin on disk tests (with steel disk and epoxy pin) and also on wear behavior under abrasive conditions (the steel disk covered with abrasive paper). The ultra-sonication was made in various ways and the results of tribological analysis are presented respecting the ultra-sonication path.

Keywords: epoxy, starch, ultrasounds, wear

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Tribological analysis of fabric reinforced epoxy composites

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Thermosetting resins are extremely used in application in which reinforcements are required due their sol-gel behavior which is allowing the immersion of the reinforcement elements. As the epoxy resins are the most versatile polymers they are usually used to obtain reinforced parts or structures for sport, domestic or transportation purposes. Generally they are used to cover fiberglass agglomerations (uniformed or ununiformed) which are strengthening the structures and improving the mechanical behavior of final product. Due to their properties the fabrics are indicated when the goal is to achieve sinuous surfaces or shapes of final products together with the advantage that fabrics, due to their structure, are keeping the spatial distribution of the fibers. In this regard it is interesting to investigate the way to use fabrics (made of various fibers) in order to improve one property or other of the final material or structure. More than that, it is good to know if there exists any opportunity to use a fabric reinforced polymer as an electric capacitor. The materials used for this study had been formed by a modified lay-up method with epoxy resin or filled epoxy resin as matrix and various fabrics as reinforcements. All the fabrics used to form the materials are woven simple type fabrics even if there might be necessary to study the effect of various fabric geometry over the final properties of materials. Four types of fabrics were used namely carbon fiber, Kevlar, fiberglass and a hybrid fabric made of carbon fiber, Kevlar, fiberglass in which thin wires of cooper were uniformly placed. The tribological behavior of materials had been developed on the pin-on-disk geometry taking into account the fact that the sliding velocity may by parallel with or perpendicular on the reinforcement layer. In the first case the main contribution belongs to the fibers while in the second the main contribution belongs to the matrix-reinforcement interface. The pin-on-disk geometry (with steel disk and composite pin) was used to analyze abrasive wear with the disk covered with abrasive paper.

Keywords: epoxy, fabric, friction, wear

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Flammability of vegetal oils on hot surface

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There is a tremendous pressure in the research world to replace mineral oils as this resource could be extinguishing sooner as scientists have been lately be estimated. The vegetal oils could be solution for this problem but their atypical behavior and their particular set of properties constrain the users to do tests for certifying their quality, especially for particular applications.

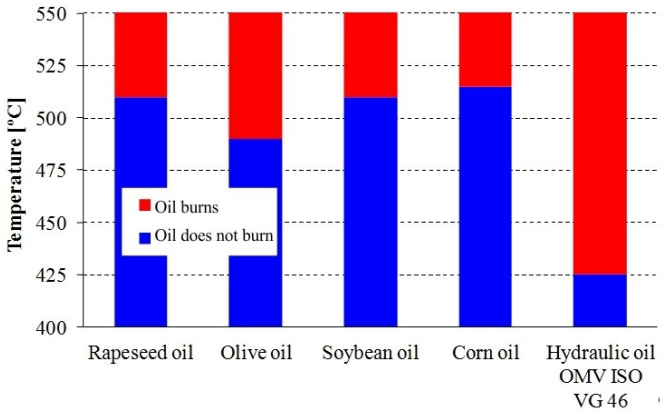
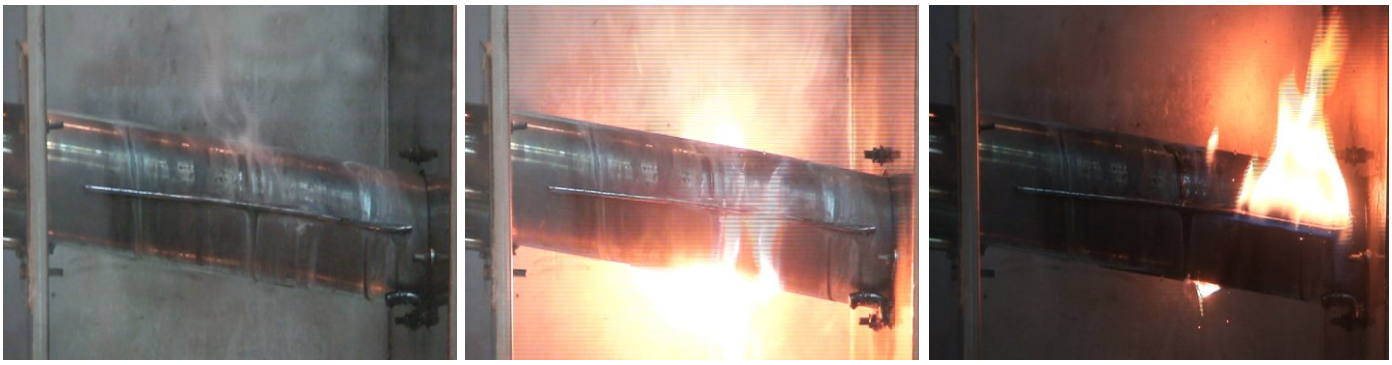


Fig. 1. The ignition temperature of the tested oils on hot surfaces (tests done according SR ISO 20283:2004, accuracy ±5ºC)

This paper presents the results of testing several vegetal oils for ranking them taking into account their flammability characteristics on hot surfaces. Tests were done according to the procedure included in SR EN ISO 20823:2004, with the help of test equipment designed by one of the author, in order to have automation and security during the tests. The testing method is designed to "imitate" the worst scenario that could happen when fluid leakage could reach hot surfaces (the causes of having hot surfaces near fluid reservoirs or pipes could be technological ones or the results of generate abnormally high temperatures, e.g. from friction processes). All oil grades were tested under the standard conditions (10 ml ± 1ml of tested fluid dropped on the hot manifold in 50 s±10 s, initial oil temperature: 20…25ºC). The ignition temperature for the vegetal oils is in a narrow range, this being, with high probability, due to the similar composition in fat acids.



1st second 2nd second 9th second

Fig. 2. Rapeseed oil tested on the manifold having a temperature of 530ºC±5ºC

Keywords: vegetal oil, rapeseed oil, olive oil, corn oil, soybean oil, flammability on hot surface.

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Virtual evaluation of manufactured surfaces – to use 3D data to predict performance

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The manufacturing and finishing of gears include several processes such as grinding, hobbing, shaving, honing, shot peening and phosphating. For the automotive industry it is a constant challenge to improve durability and reduce fuel consumption - still being cost effective using robust processes for mass manufacturing. A better knowledge of the properties of the manufactured surfaces in gears, and especially how they interact in different combinations is an important knowledge when designing gearboxes for the future. The following paper proposes a way to use simulation software in combination with 3D measurement data to create a performance matrix to use for choosing between known methods, but also a way to predict the behavior of new combinations of process parameters in an early stage of the design process. The used simulation method to predict the ability of a given manufacturing process to resist wear is a rough contact model including elasto-plastic behavior of materials, computing parameters usable for ranking of performance. Take off point for the study is a combination of industrial knowledge and sometimes the feeling for what combinations are better than others. To create this virtual screening procedure parts from several manufacturers with different processes are measured to gather surface data. In total up to 20 different surface combinations are evaluated. As a result the simulation strategy used emphasizes: i) a quick way to evaluate a new process ii) knowledge of the properties of used processes iii) new light to the beneficial secrets of shot peening and phosphating of surfaces. The future work for the developed performance matrix using this approach will be validation using a rig test to compare the virtual performance screening with fatigue testing, looking for pitting damages as an indicator of performance linked to surface stress and lifetime.

Keywords: gear manufacturing, 3D topography, virtual evaluation

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Modern Methods for Estimation of Triboresistance during Nanoscanning of Fiberglass Surfaces

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This paper deals with the processes taking place during nanoscanning of surfaces of fiberglass samples. Nanoscanning has been performed with the use of an atomic force microscope which is a high-resolution scanning probe microscopy system. Atomic force microscopy (AFM) can be used for scanning both conductive and non-conductive samples. Analysis of the data obtained from the AFM system can provide us not only with the topographical image of the scanned surface, but also with information about the forces of interaction between the sample and the probe, particularly about the friction forces. Understanding of the processes taking place during nanoscanning, including friction processes, gives us the opportunity to interpret the obtained results more correctly. The aim of this research is to develop a method for estimation of friction parameters during the probe and surface interaction in scanning probe microscopy systems (SPM). Particular attention is given to estimation of triboresistance [1], which allows us to investigate how the sample resists to the influence of the tip on it. This resistance depends not only on the forces of interaction between the tip and the sample, but also on the internal friction in the surface layers of the sample. Triboresistance helps us to estimate, in some degree, the internal friction in the scanned sample.

To estimate triboresistance, in the previous paper [1, 2], we have introduced action parameters. According to our method, we have produced cumulative sums of rows and columns of measured data. After that, we define the maximum value of spectral energy density, the maximum cumulative value of spectral energy density, and the maximum frequency corresponding to the maximum value of spectral energy density. Then we define two pairs of action parameters: one pair for data in columns, and one pair for data in rows. Finally, we define triboresistance using the obtained action parameters.

In this paper, triboresistance has been estimated for the fiberglass samples scanned with the atomic force microscope.

Keywords: triboresistance, surface nanoscanning, scanning probe microscopy, action parameters, internal friction.

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Tribological study of some multilayered ceramic structures in the aeronautical industry

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The „hot parts" (combustion chamber, blades and shutters, cover plates, etc.) of the turbo engines are subject to wear factors with pyrolyzed particles at speeds of up to 5-6 Mach, corrosion, temperature, thermal shock, adhesive wear that may act simultaneously and harshly at high values.

Increased performance and endurance of the turbo engines can be obtained by using multilayered micro and nanostructured ceramics.

This paper presents TBC- thermal barrier coating- elaborated structures based on Zirconia that is doped with Ytrium and Cerium oxides, as well as rare earths, micro and nanostructured.

Tribologycal testing will illustrate the behavior of TBC layers at quick thermal shock-heating/cooling speeds of 70°C/s – the most perturbing wear factor for ceramic layers, as well as its response to adhesive wear, wear that occurs at the adjustable nozzle in turbo engines, through the relative motion of the shutters and cover plates.

Thermal shock testing will be performed on a unique installation of authors and will underline micro structural modifications that are dynamic induced by the gradual increasing of the testing temperature.

The thermal shock behavior of the TBC elaborated structures, crucial to evaluating ceramic materials for modern turbo engines, will be completed by adhesive wear testing that is associated with the friction of shutters and cover plates conjugated surfaces.

Keywords: turbo engines, adhesive wear, quick thermal shock, TBC

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Study of Torque and Thrust of needle roller bearings

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Needle roller bearing has a small diameter and large length of roller compared with other roller bearings. Therefore, this bearing has higher load carrying capacity and stiffness. In addition, this bearing is suitable for reciprocating motion because of small inertia. Beside, in case of solid type needle roller bearing, outer ring, inner ring and needle with the retainer of this bearing can be separated, these parts can set up to an axis or a housing, respectively. On the other hand, there occur skewing phenomena in the rolling action of needle rollers in a bearing. As a result, thrust will occur in the needle roller bearing causing from skewing which take place in the direction to the axial. Therefore it is considered that performances of this bearing under various operating conditions are not clear sufficiently.

In this study, influences of load, number of revolution and eccentricity of load on the torque and thrust of needle roller bearing were investigated experimentally. In experiments, single type and double type of bearing were used.

Keywords: needle roller, torque, thrust

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Friction of W-DLC(H) - testing in laboratory and motorcycle engine

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Automobiles constitute a significant part of motor vehicles globally. It is believed that the overall number of cars around the world will exceed 2.9 billion by 2050. Bearing this number in mind the reduction of friction in internal combustion engines by few per cent could not only bring more effective powertrains but also save energy and money.

DLC coatings exhibit excellent wear resistance along with high hardness, thereby allowing their potential application in combustion engines. On the other hand, the chemical interaction with commercially available oils is very limited, which typically results in higher friction. The aim of this study is thus to understand tribological behaviour of DLC in lubricated contacts.

Hydrogenated DLCs doped with tungsten were deposited by DC magnetron sputtering in reactive atmosphere. Four targets in a semi-industrial chamber (Teer) were used: chromium to deposit adhesion improving interlayer (app. 250 nm thick), two pure graphite targets and one graphite target with embedded tungsten pellets placed into erosion zone. The tungsten content was 2-20 at.%, hydrogen content was 0-36 at.% resulting in amorphous morphology or nanocrystalline with tungsten carbide nanograins embedded into amorphous carbon matrix. The hardness of DLC increased from 10 to 15 GPa with increasing W content.

The coatings were tribologically tested in commercially available oil (Motul 5W-40) using pin-on-disc tribometer (CSM Instruments). Selected coating was eventually applied on valve lifters and tested in a Yamaha YZF-R6 motorcycle engine. The wear rate of coated surfaces after laboratory and engine tests was very low with almost no wear marks, contrary to scratched non-coated steel valve lifters. Raman spectroscopy, HR-TEM and TOF-SIMS was used to identify coating structure, sp^2 /sp^3 ratio and tribolayer formed on the coating surface. Despite chemical inertness W-doped DLC(H) coatings react with oil additives forming a very thin (< 5 nm) tribolayer.

Keywords: Tribology, DLC coating, motorcycle engine, Raman spectroscopy, Tof-SIMS

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Laboratory Investigations about the Mechanisms of Aluminium Transfer on Hot Forming Tools

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The production of complex-shaped components from aluminium alloys offers a combination of light weight and mechanical properties very attractive for the transport industry. However, the efficiency of the process is limited by complex tribological interaction between tool and workpiece: galling in aluminium forming is known to occur at temperatures as low as 100 ºC, and may increase in severity at higher temperatures, resulting in lower part quality, intensive tool maintenance and increased cost.

In this work, the mechanisms resulting in transfer of aluminium on forming tools have been analised by means of laboratory tests. The influence of chemical affinity in aluminium adhesion has been studied in a series of high temperature contact tests, in which a 99% Aluminium ball has been pressed against tool surface and separated at low velocity, measuring the force used in breaking the interface. On the other hand, the role of mechanical interaction has been investigated using ball-on-disk sliding tests at high temperature, using tool steel disks with different surface finish against an aluminium alloy counterpart.

Results show that both chemical affinity and mechanical interaction have relevant contribution in the phenomenon of material transfer, and any solution designed to minimise adhesion must take into account the combination of both factors.

Keywords: wear, metal forming, aluminium, high temperature, adhesion

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TiO_2 and TiO_2/Ag nanotubes as coatings for modern dental implants

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The insertion of dental implants is a routine procedure in dentistry nowadays. Treatment with dental implants allows outstanding aesthetic reconstruction with optimal masticatory function following tooth loss. Modern dental implants usually have bioinert titanium surfaces and the healing rates are over 97 %. Although the modern dentistry has high success rate in the implant technology, many studies have demonstrated that they do sometimes fail due to peri-implant infection. Epidemiology and etiology of early infection, which occurs before osseointegration, or late infection which occurs after prosthetic rehabilitation, indicate on important role of implant materials in these risks. As implant material differ in the ability of oral bacteria and yeast to form biofilms and colonize them, they may reflect greater or lesser susceptibility for occurrence of peri-implant infection. It is believed that bacteria and fungi adhering to the surface of the implant and forming biofilm play a pivotal role in early peri-implant infection. They usually are difficult to treat, since biofilms show high resistance to antimicrobial agents, especially when the causative microorganism is multi-drug resistant.

Because there is still no way to complete elimination of microorganisms from the surface of the implants after biofilm-associated infections has occurred, it is necessary to develop effective prevention methods against microbial adhesion and subsequent invasion. Modification of titanium implants with the compounds possessing antiadhesive or direct biocidal activity, as it is proposed in the research project, seems to be an important strategy to prevent early peri-implant infection and their later complications.

Given the fact that the vast majority of dental implants that come into use are made of titanium, and on their surface there is always present 2-5 nm TiO2 layer (which is often formed in few seconds after exposing pure titanium or its alloys to air), and that TiO2 exhibits antiseptic properties (especially when doped by Ag, Au, Cu and Fe), it seems only reasonable and natural to coat titanium implants with titanium dioxide layers doped with metallic silver nanoclusters. It should be borne in mind that TiO2 coatings have a positive impact on the process of osseointegration. The

presence of a TiO2 coating at the implant site will highly likely promote above-average proliferation of cellular bone matrix and lead to well concrescence between the bone and the implant. At the same time doping of oxide films with metallic silver will lead to dispersion of Ag clusters on the entire layer and will positively influence the effectiveness of their antibacterial activity.

The results of studies on: (a) synthesis of TiO_2 and TiO_2/Ag nanotubes, (b) surface structure and morphology, (c) photocatalytic activity and wettability of TiO_2 andTiO_2/Ag nanotubes, (d) biological activity of TiO_2 and TiO_2/Ag nanotubes, and (e) abrasion and friction of TiO_2 and TiO_2/Ag nanotubes coatings, will be presented.

Keywords: dental implants, titania nanotubes, silver nanoclusters, biological activity, abrasion, friction

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